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Orbit Analysis Tools Software Version 1 for Windows User's Guide

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13. ABSTRACT (Maximum 200 words) The Orbit Analysis Tools Software (OATS) is a mission planning and analysis tool for earth-orbiting satellites. OATS evolved from a collection of software tools developed by the Astrodynamics and Space Applications Office of the Naval Center for Space Technology (NCST), located at the Naval Research Laboratory (NRL) in Washington, DC. There have been three previous versions of OATS that are available to the public for use on a Macintosh computer. This release of the OATS program is a revised and expanded version for use on the Windows 95 and Windows NT operating systems. The program's function is to perform satellite mission and coverage analysis using numerical and graphical techniques to analyze and display earth coverage data and ground-to-satellite geometrical parameters. Satellite ephemerides can be computed by any of the four orbit propagators provided with the program, or they can be imported from an external source. Six commonly utilized map projections are available to plot computational results. Some of the program enhancements for Version 1 include the typical Windows point-and-click interface through the use of menu options and toolbar buttons. This latest release also provides a real time propagation option for generating the ephemeris data. This feature simultaneously generates the ephemeris and graphically displays the current satellite position and tracks on a map in real time. A series of validation tests of Version 1 OATS for Windows were conducted for functionality and accuracy. The verification method was accomplished by making comparisons between computations and displays of Version 1 OATS for Windows and the previously validated Version 5.0.4 OATS for the Macintosh. The new Windows interface was written using Visual C++, and the OATS program runs on Windows 95, 98, or Windows NT operating systems which requires 8 MB RAM, 5 MB hard disk space.			
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Chapter 1

Introduction

1.1 Product Summary

The Orbit Analysis Tools Software (OATS) is a mission planning and analysis tool for earth-orbiting satellites. OATS evolved from a collection of software tools developed by the Astrodynamics and Space Applications Office of the Naval Center for Space Technology, located at the Naval Research Laboratory in Washington, DC. There have been three previous versions of OATS that are available to the public for use on a Macintosh computer. This release of OATS version 1 is strictly for use on the Windows 95, 98 and Windows NT operating systems.

OATS supplies a dualistic analytical environment, providing graphics-oriented analytical tools as well as tabular output that can be used to address many of the questions commonly posed by designers planning a new satellite system or by managers wishing to assess the performance of an existing system. Its particular strength is the quantification of satellite coverage available from a user-defined configuration of satellites.

This manual is intended to provide an overview of OATS that will permit potential users to determine if the program meets their analytical needs. It discusses all program functions, shows how to access the various capabilities of OATS, and presents what the user should expect to see when the program options are exercised. To complement its overview function, this manual is organized to provide fast access to information on single program capabilities. OATS is user-friendly and many users may not require documentation; however, this manual will provide fast access to many of the details of program operation and will discuss strategies for efficient use of the program.

The major analytical capabilities and outputs of OATS include:

- Computation of pass parameters for a satellite and ground station, including azimuth, elevation, range, and range rate as a function of time, the times of acquisition of signal (AOS) and loss of signal (LOS), and signal attenuation.
- Computation of coverage statistics for a set of targets under a system of satellites with user-defined attitudes using an optional set of ground stations for communication links. Statistics include rise and set times, duration of coverage, outage, and revisit times, and maximum, minimum, mean, and standard deviation of coverage, outage, and revisit times.
- Computation and display for a system of satellites and ground stations of coverage data on a global grid. Display can be as a contour mapping of coverage isochrones or as a density mapping of regions of equal coverage. Capabilities exist for comparison of multiple sets of graphical coverage data.

- Creation of global maps, using a selection of two- and three-dimensional map projections.
- Creation of satellite ephemeris data, using a selection from four different orbit propagators and six orbit element data set formats. Provisions exist for fast display and inspection of ephemeris files.
- Display satellite geographic data, including position, field-of-view (FOV), ground tracks, and coverage swaths.
- Compute and display the overlap of instantaneous multiple satellite FOVs, defined in OATS terminology as snapshots.
- Display ground geographic data, including target and ground station positions, ground station fields-of-view (FOV), and Earth shadow data.
- Display of all mapped data with user-controlled colors, line widths, shading densities, and icon sizes.

1.2 System Requirements

The system on which you will be installing OATS needs to fulfill the following minimum requirements:

- Windows 95, 98 or Window NT operating system
- 8 MB RAM
- 5 MB available hard disk space
- 3_ inch floppy drive, if installing by diskette

1.3 Installing OATS

The OATS installation should take five minutes or less, depending on the resources of the system.

The software can be installed from a set of two 3_ inch diskettes which may be obtained from the authors. Alternatively, the installation is available through a self-extracting executable that may be downloaded from the internet via the homepage of the Naval Research Laboratory:

http://ssdd.nrl.navy.mil/www/oats/oats_welcome.htmlx

To install from diskettes, follow these instructions:

1. Insert disk 1.
2. In the File Manager or Windows Explorer, select the drive containing the disk.
3. Launch Setup.exe from this directory.
4. Follow the installation instructions as they appear on the screen.

Otherwise:

1. Download OatsSetup.exe from the aforementioned web site.
2. Launch OatsSetup.exe from the directory to which you downloaded.
3. Follow the installation instructions as they appear on the screen.

1.4 Chapter Descriptions

Chapter	Description
Chapter 1: Introduction	Summarizes the capabilities of OATS and describes the installation procedure and documentation content.
Chapter 2: User Interface	Familiarizes the user with the OATS Windows environment.
Chapter 3: Orbit Propagation	Explains the use of the orbit propagators and the generation of ephemeris data.
Chapter 4: File Management and Inspection	Describes the activation and inspection of ephemeris and attitude files.
Chapter 5: Coverage	Shows how to perform various satellite coverage analyses.
Chapter 6: Graphics	Depicts the methodologies of plotting maps and other objects, selecting those objects' attributes, and manipulating graphics.
Chapter 7: Saving Your Work	Describes how to preserve maps, scenarios, and OATS environments for future use.
Chapter 8: File Formats	Discusses the format of self-generated and external files.

Chapter 2

User Interface

OATS employs a typical Windows point-and-click interface through the use of menu options and toolbar buttons. In this chapter the different parts of the OATS window are described.

2.1 Title Bar

The title bar displays your filename (“Untitled” if no file is currently selected) next to the application name.

2.2 Menu Bar

The menu bar features nine drop-down menus:

- File : Standard Windows File options are available here as well as a recent file list and the option to adjust OATS parameters.
- Edit : Standard Windows Edit options in addition to a graphics selection option and a text drawing option are available in this menu.
- View : From this menu one can activate/deactivate the toolbars, graphics window, text window, and locator mode, zoom in and out of the document window, and clear the document window of all plotted items.
- Ephemeris : The selections in this menu allow ephemeris files to be generated, activated, viewed, and position checked.
- Attitude : Attitude files can be activated and pointing checked from this menu.
- Coverage : These menu choices allow coverage files to be created and compared.
- Plot : All plotting functions are available from this menu.
- Attributes : The settings for lines, shading, and icons can be adjusted with the these menu choices.
- Help : The About OATS choice is currently the only one available in this menu. Future releases will contain the option to view help documentation.

Menus can be accessed either by clicking on them with the mouse or by certain keystrokes. The Alt key will place focus on the first menu title, the arrow keys can be used to navigate through the menus, and the Enter key selects the highlighted menu item. Alternately, a specific menu can be dropped down by pressing the Alt key and the letter in the menu title that is underlined, and a menu item can then be selected by typing its underlined letter. Some menu items are listed with an accelerator, a keystroke combination that acts as the equivalent of selecting the menu item.

2.3 Toolbars

Several of the menu options are available in the form of toolbar buttons. Each toolbar can be hidden or made visible either through the choices in the *View* menu or via a pop-up menu seen by right-clicking on the toolbar area of the application window.

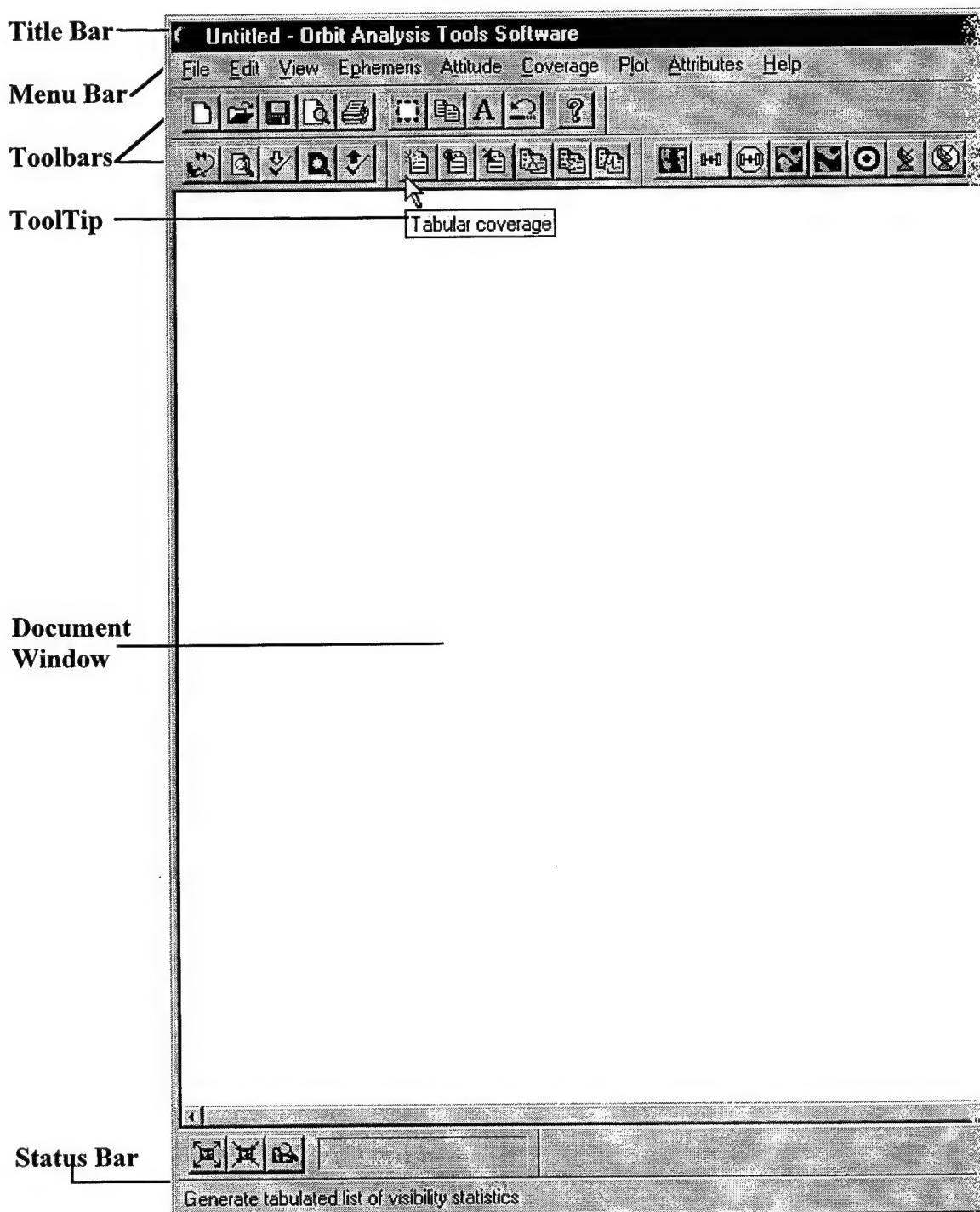
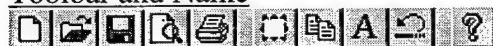


Figure 2.1. The OATS user interface

The following table gives the names of the toolbars and the individual buttons contained within them. Descriptions of the specific functions of the buttons can be found in later chapters.

Toolbar and Name



Standard Toolbar

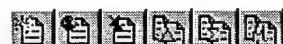
Button names (from left to right)

New, Open, Save As, Print Preview, Print, Select Graphics, Copy, Add Text, Undo, About OATS



Data Toolbar

Generate Ephemeris, Ephemeris Files, Position Check, Attitude Files, Pointing Check



Coverage Toolbar

Tabular Coverage, Graphical Coverage, GS Look Angles, Difference, Sum, Mean



Plot Toolbar

Map, Satellite Position, Satellite FOV, Satellite Tracks, Satellite Swath, Target Position, Ground Station Position, Ground Station FOV, Density Contours, Line Contours, Snapshot, Sun and Shadows



Attributes Toolbar

Lines, Shading, Icons



View Toolbar

Zoom Out, Zoom In, Locator Mode [Locator Window]

2.4 ToolTips

A ToolTip is a small pop-up window that displays a single line of descriptive text giving the purpose of the item to which the mouse is pointing. A ToolTip will appear after resting the mouse pointer on a toolbar button for a few seconds.

2.5 Document Window

The Document Window contains all of the user's graphical output.

2.6 Status Bar

Information about an item underneath the mouse pointer may be displayed on the status bar. The status bar can be hidden by the same method as hiding toolbars.

2.7 Graphics Window

The *Graphics Window* is a dialog that allows the user to manipulate graphical output seen in the Document Window. It can be activated through the *View* menu and deactivated the same way or by clicking on the *Close* button in the dialog. If the user so chooses, this dialog can remain open for the duration of the program execution, be moved to any location on the screen, or be minimized to the bottom of the screen.

The names of the plotted items are displayed in the *Graphics Window* for the user to select and rearrange at will. The *Delete* button will remove any selected graphical item from the screen. The *Send to Back* and *Bring to Front* buttons move the selection behind and in front of all other plotted graphics, respectively.

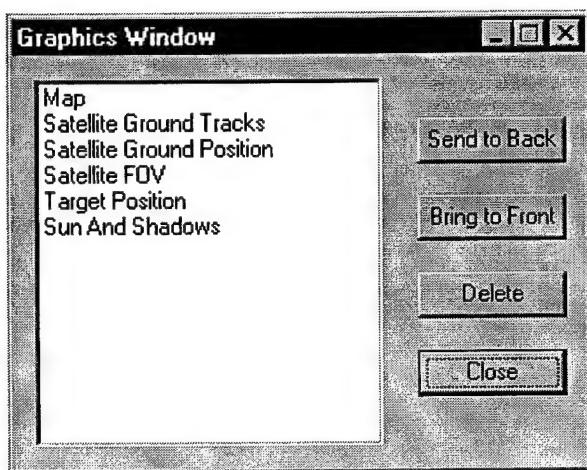


Figure 2.2. Graphics Window

2.8 Text Window

The *Text Window*, like the *Graphics Window*, is activated and deactivated through the *View* menu and can be deactivated from its own *Close* button. Its purpose is to display tabular data produced by any of the analytical functions in OATS. This dialog may be continually open, moved about the screen, and/or minimized. The window will automatically become visible if the user executes a data-producing procedure that he/she previously designated for on-screen echo. (See next section).

2.9 OATS Parameters

This dialog, launched from the *File* menu, allows the user to set parameters that dictate how data is calculated and viewed. The user can select which procedures should automatically display resulting data to the screen while simultaneously writing the data to a file. The on-screen data can be cleared or appended to when output from another designated procedure is generated. A summary of graphical data can be displayed following the generation or combination of such coverage files. Finally, the accuracy tolerance for certain calculations can be set in this dialog.

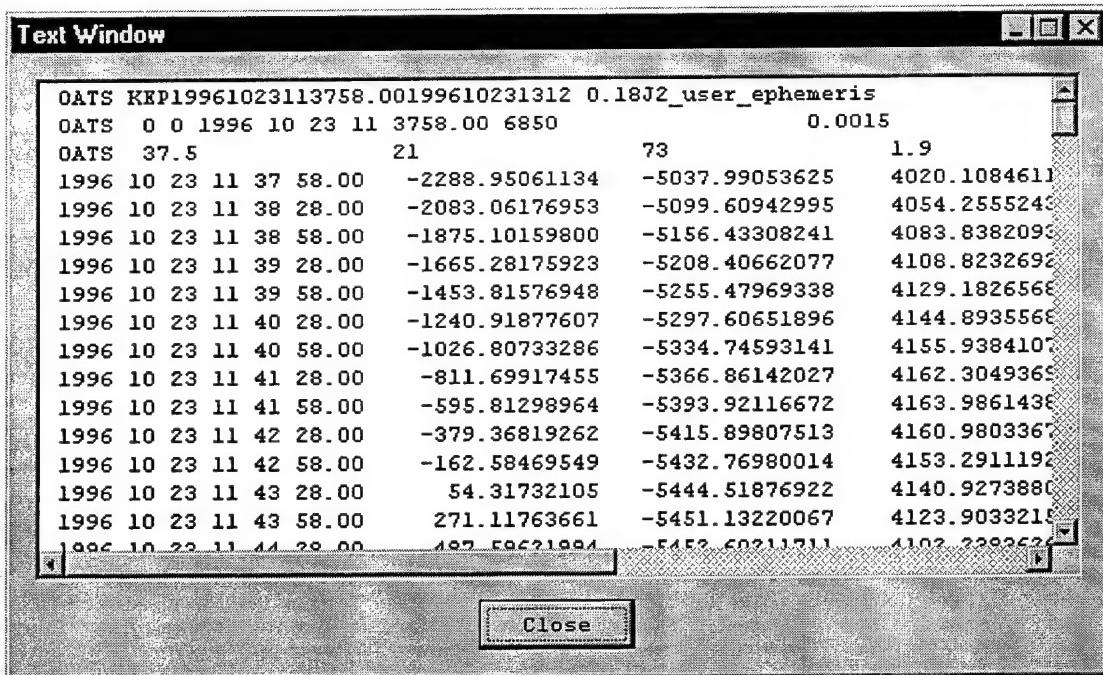


Figure 2.3. Text Window

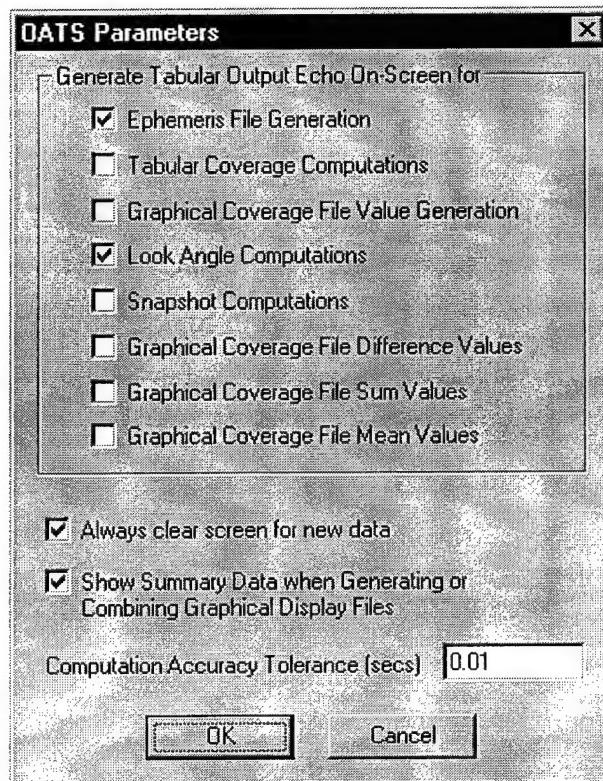


Figure 2.4. OATS Parameters dialog

Chapter 3

Orbit Propagation

OATS combines orbit propagation models with numerical and graphical coverage analysis algorithms. The design philosophy of OATS has been to separate the orbit models from the analysis processes. The primary reason for selecting this architecture is that an arbitrary number of different orbit propagation models can be added to the program without affecting any of the analysis code. This architecture also makes it possible to perform analysis on an imported ephemeris generated by an external program that might use a propagator not available through OATS. Thus, the user must always have satellite ephemerides available before proceeding with any of the OATS coverage analysis functions. Although it is expected that a typical user will employ the OATS functions to generate ephemerides prior to performing analysis, imported ephemeris files can be used if they follow a prescribed format (see Section 8.2).

3.1 Propagation Models

Four orbit propagators are provided with OATS with which satellite ephemerides can be computed. The abbreviations for each of these models is the same as those used in the OATS menu system. The format for the orbital elements for each propagator is provided in Section 8.1.

- **PPT2** - This propagator uses a full Brouwer-Lyddane analytic model for propagation and requires the input of a One Line Element Set (OLES). Three different OLES formats are available including:

PME
Charlie
Z (also designated Zulu)

- **RK12** - This is a fourth order Runge-Kutta numerical integration with a WGS84 geopotential of order and degree 12. The input for this model is an osculating Cartesian state vector and an epoch for the state vector. This model requires a small integration step size to obtain accurate results (typical values range from 1 to 10 seconds). This step size is rather small for plotting and coverage analysis and tends to yield very large ephemeris files to store the data. Because of this, the user specifies the integration step size for the propagation as well as an output interval for the ephemeris data.
- **J2** - The J2 propagator uses a first order analytic theory with earth oblateness effects. The input elements are mean Keplerian orbital elements and an epoch for these elements.

- **SGP4** - This is used to propagate a Two Line Element Set (TLES) generated by USSPACECOM (formerly NORAD). The model is used for near-earth satellites, defined by USSPACECOM as having periods under 225 minutes. The SGP4 model (Reference 5) was developed by Ken Cranford in 1970. It is a simplification of the extensive Lane and Cranford analytical theory, which uses Brouwer's solution for its gravitational model and a power series density function for its atmospheric model.

3.2 Propagation Coordinate Systems

Two coordinate systems are referred to through the remainder of this section. They are Earth Centered Inertial (ECI) and Earth Centered Fixed (ECF). The fundamental plane of the ECI system is the mean Celestial Equator. The x -axis lies in the direction of the Vernal Equinox, and the z -axis points toward the North Celestial Pole. The ECF system is a non-inertial, rotating system that is fixed to the earth. The fundamental plane of the ECF system coincides with that of the ECI system. The x -axis is rotated about the Celestial Pole through the Greenwich hour angle. The effects of precession and nutation of the Earth pole are ignored. All of the analysis and plotting functions in OATS to which satellite ephemerides are input require the coordinate frame to be ECF. The output coordinate system for all of the OATS propagation options is ECF.

3.3 Orbital Element Data Entry

To set up an ephemeris generation run, choose a propagation model either from the *Ephemeris* drop-down menu or from the dialog launched when the *Generate Ephemeris* toolbar button is pressed.

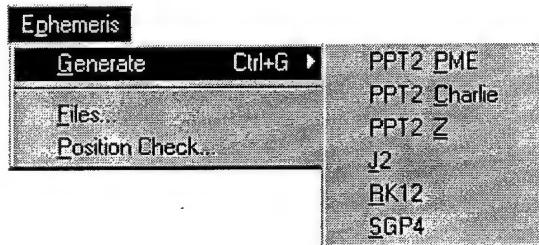


Figure 3.1. Ephemeris menu

This brings up a dialog with two tabbed windows. In the window with the Elements tab, the user can enter the orbital elements for that particular model. An explanation of the orbital element components is provided in Appendix B. Clicking on the Interval tab brings a different window to the front in which the time interval and step size can be entered.

The various input fields for all six orbital element sets are individually labeled with appropriate units, if any, and should be generally self-evident if the user understands the

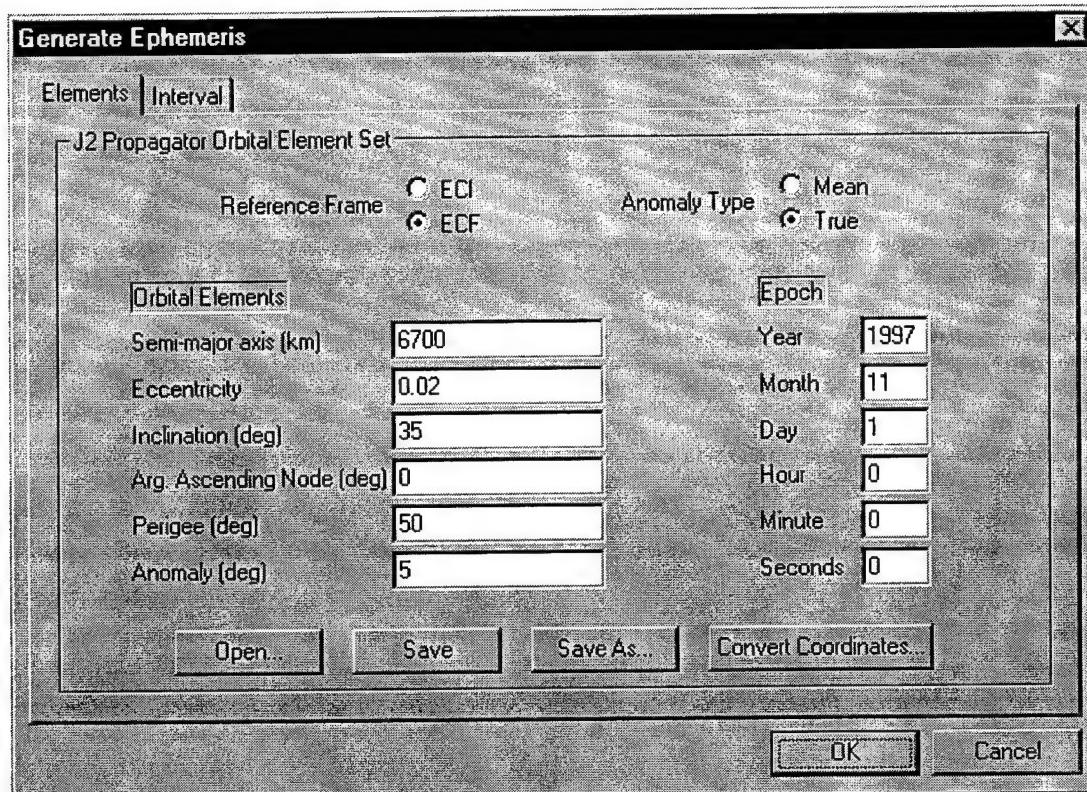


Figure 3.2. J2 Orbital Elements window

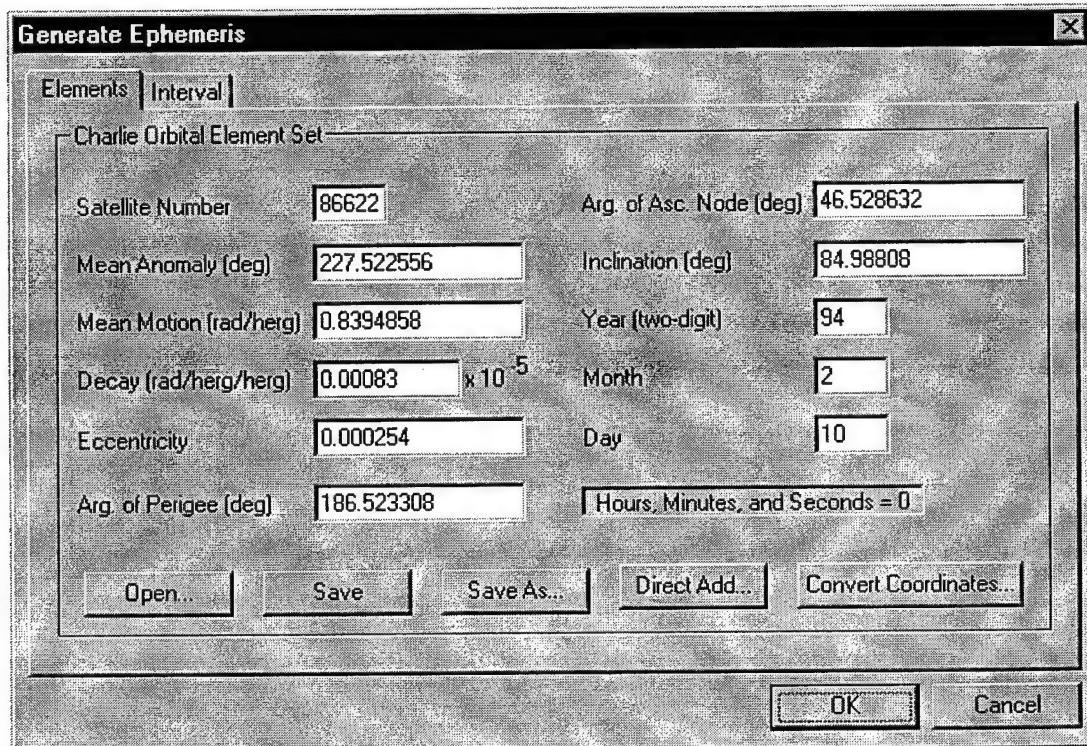


Figure 3.3. PPT2 Charlie Elements window

discussion presented in Appendix B. The J2 and RK12 Elements windows contain radio buttons with which to select the reference frame as ECI or ECF, and the J2 window has additional radio buttons for the selection of anomaly type. Note that the orbit epoch year should be entered as a four-digit year for the J2 and RK12 cases, as a two-digit year (representing the time span 1951 through 2050) for the SGP4, Charlie, and Z cases, and a one-digit year for the PME case. In the PME Elements window, the user may specify the 10-year range in which the one-digit epoch year is defined. The RK12 dialog contains a place to input the Integration Time Step, which is the interval used by the orbit propagator to perform computations. This interval should not be confused with the ephemeris interval, also known as the time step.

3.4 File Input / Output

Each of the orbit element dialogs contains the buttons *Open*, *Save*, and *Save As*. *Open* allows the user to locate and utilize an existing input file of orbital elements in any directory. A set of orbital elements can be saved to the currently active file using the *Save* option or to a new file by pressing the *Save As* button. In the case of overwriting an existing file, the user will be asked permission prior to writing to the file.

3.5 Direct Add

The Elements window for the PME, Charlie, Z, and SGP4 models include an additional button for the *Direct Add* of orbital elements. In their native format, OLES and TLES exist in a condensed form. Thus, the *Direct Add* feature is available for the case where the user wishes to enter the elements in such a format. By clicking on the *Direct Add* button, a dialog appears in which the user can enter the OLES or TLES manually or by copying the data from another application and pasting it into this one. The expected format for the elements set is visible on the dialog, as the format varies for each model. Once the *OK* button is pressed, the data from the *Direct Add* dialog is interpreted into the appropriate fields in the Elements window provided the data is in correct format. The user is alerted if the format of the element set is erroneous.

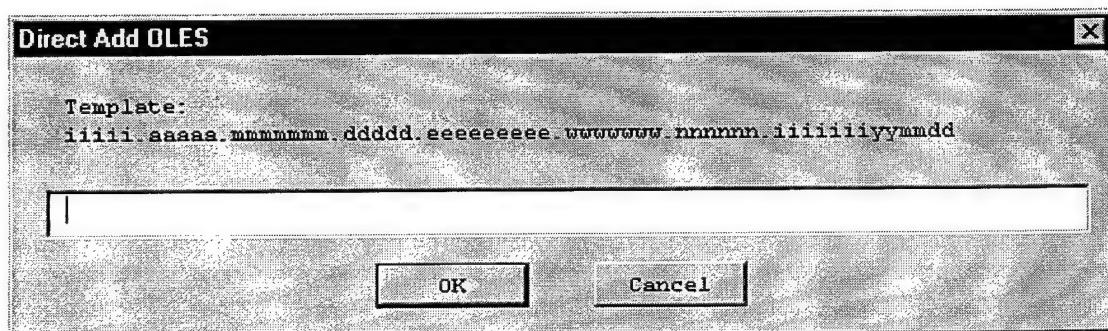


Figure 3.4. PPT2 Charlie Direct Add dialog

3.6 Coordinate Conversion

A limited set of orbit element coordinate conversions is made available through OATS. The possible conversions can be seen graphically in Figure 3.5, the dialog that is presented to the user after pressing the *Convert Coordinates* button located in the Elements window. The user should note that no orbit element coordinate conversion is going to be exact. For proper and precise propagation of an orbit, the orbit element set must be matched to the propagator model for which the elements were computed. However, these coordinate conversions serve several useful purposes:

- They provide a more intuitive look at an orbit specified by an OLES or TLES by presenting it in a Cartesian or Keplerian format.
- They make possible a comparison of two differently specified orbits by providing a common format for orbit element display, even if the computed values are only very close approximations.
- They provide a basis for transforming an orbit element set so that it can be used by another piece of software that cannot handle some of the orbit propagation models available with OATS.

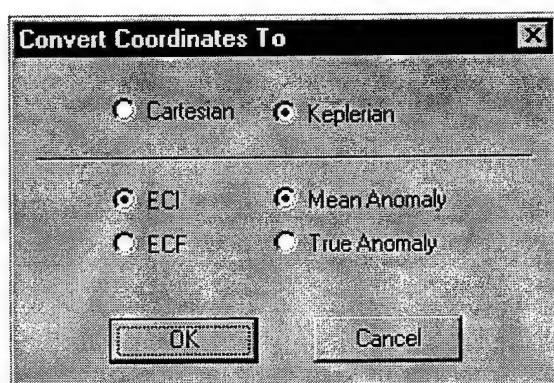


Figure 3.5. Convert Coordinates dialog

An orbit element coordinate conversion is performed by first entering the elements in the appropriate dialog for the model from which the user is converting. In the dialog resulting from clicking on the *Convert Coordinates* button, select the elements set to which the coordinates should be converted and hit the *OK* button. A dialog for the new propagation model will appear with the converted coordinates in the appropriate locations. From this dialog the user may alter and/or save the data, convert the coordinates further, set the interval, and/or propagate the orbit if desired.

3.7 Setting the Interval

When the entry of orbital data in the Elements window is complete, the user should click on the Interval tab to bring the Interval window to the front. The start and stop times for the generated ephemeris file are entered here as well as a step size in seconds. Clicking on the *Use Epoch* button sets the interval start time to the epoch entered in the Elements window. The stop time can be set using the number of revolutions by clicking the *Use*

Revolutions checkbox and entering a number in the edit box below. The user may verify the stop time by clicking the *Show Stop Time* button, which will display the stop time as computed by Kepler's equation. However, this inspection is not required — the stop time is automatically computed from revolutions, if so chosen, when the user clicks on *OK*. Negative values of revolutions are unacceptable as is a manually entered stop time that implies an orbit propagated backwards in time.

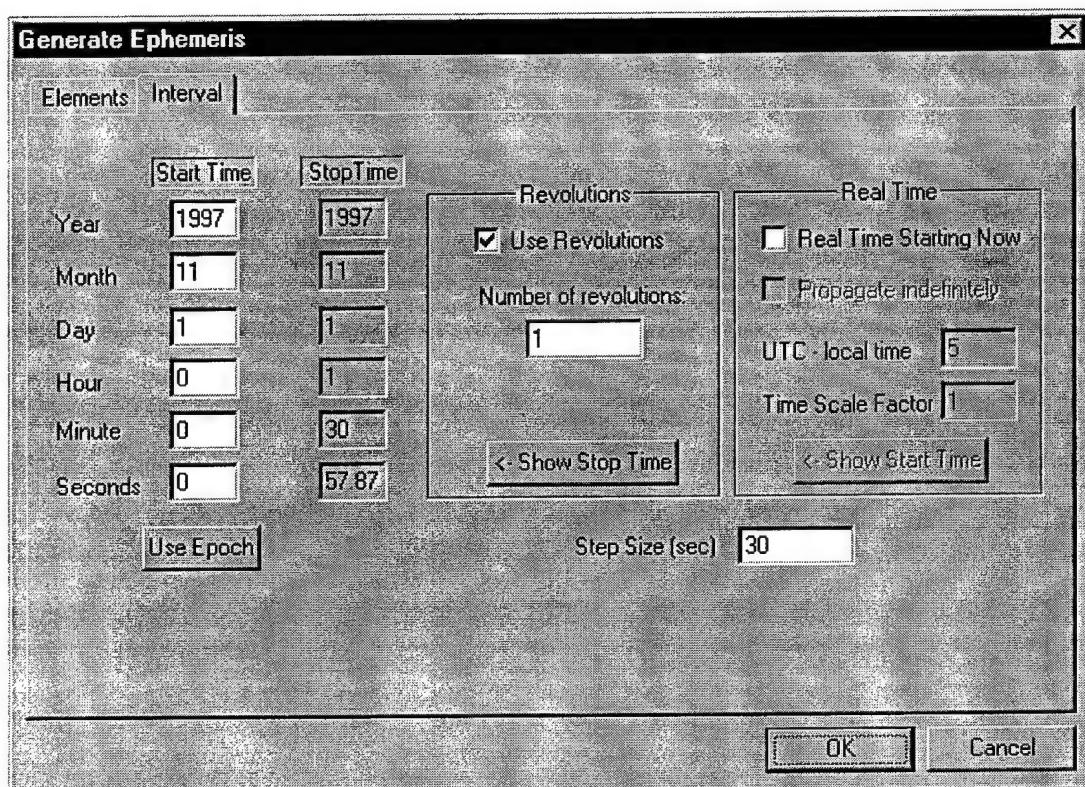


Figure 3.6. Interval window

3.8 Real Time Propagation

The real time propagation option in the Interval window provides an alternate method of setting the interval as well as generating the ephemeris data. This feature simultaneously generates the ephemeris and graphically displays the current satellite position and tracks on a map in real time. In order to use the real time feature, a map must be plotted prior to bringing up the *Generate Ephemeris* dialog (see Section 6.1).

Real time propagation is activated by clicking the *Real Time Starting Now* checkbox. The start time is then computed as the current UTC time using the computer system clock and the user-specified *UTC – local time* difference. The time is displayed for the user's benefit, but the actual start time used in the calculations is the time at which the user clicks *OK* to initiate the run. The stop time can be set by manually entering it in or using revolutions as described in the previous section. However, if the *Propagate Indefinitely* option is selected the ephemeris is generated until the user stops the run by clicking

Cancel in the progress dialog seen in Figure 3.8. A *Time Scale Factor* may also be specified in order to accelerate the speed at which the data is calculated and graphically displayed. A scale factor of 1 indicates the updates will occur in real time according to the step size, whereas a scale factor of $n > 1$ will cause the display to update n times as fast as real time.

3.9 Generating an Ephemeris File

After all data have been entered in both the Elements and Interval windows, click the *OK* button at the bottom of the dialog to begin propagation. Clicking on the *Cancel* button will close the dialog and neither run the propagator nor preserve the entered data for future use. After clicking on *OK*, a dialog will appear in which the user may specify the directory and filename of the ephemeris file about to be generated. Exiting this dialog with an *OK* will initiate propagation and write the results in the ECF coordinate system to the specified file. If the *Cancel* button is pressed, the elements data is still preserved but no ephemeris file is created. If the echo on-screen parameter for generating ephemeris files was previously selected in the *OATS Parameters* dialog, a text window will appear (if not already visible) to display the ephemeris data as it is simultaneously being written to the file only if real time propagation is not being used. A progress dialog similar to that seen in Figure 3.7 is displayed while the data is being written to the ephemeris file. In the case of real time propagation, the progress dialog seen in Figure 3.8 is shown instead. The user may click on the *Cancel* button in the progress dialog to terminate the propagation run at any time. After the propagation is complete, the file is automatically added to the list of active ephemeris files. The significance of this list is explained in Chapter 4.

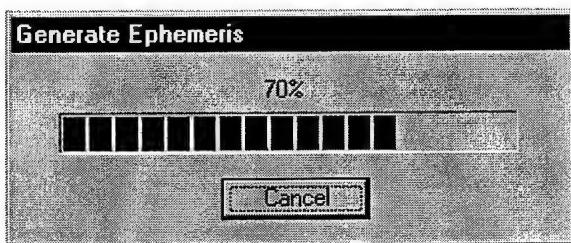


Figure 3.7. Progress dialog for generating ephemeris files

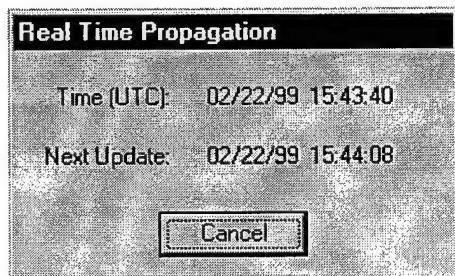


Figure 3.8. Progress dialog for real time propagation

Chapter 4

File Management and Inspection

One of the cornerstones of operating OATS involves the use of files to supply time-dependent data, specifically those files used to provide time dependent ephemeris and attitude data. The *Ephemeris* menu (Figure 3.1), the *Attitude* menu (Figure 4.1), and the *Data* toolbar provide interfaces that allow the user to open files for plotting and coverage analysis activities, to inspect files prior to opening them for analysis, and to use the files to make spot checks of position and attitude based on the file data.

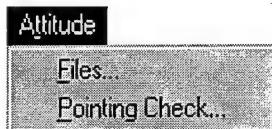


Figure 4.1. Attitude menu

4.1 Ephemeris File Activation

Selecting *Files...* from the *Ephemeris* menu or clicking on the *Ephemeris Files* toolbar button launches the dialog seen in Figure 4.2. The list on the right displays the names of ephemeris files activated either by generating the file as described in Chapter 3 or by selection of the file from the directory tree displayed on the left.

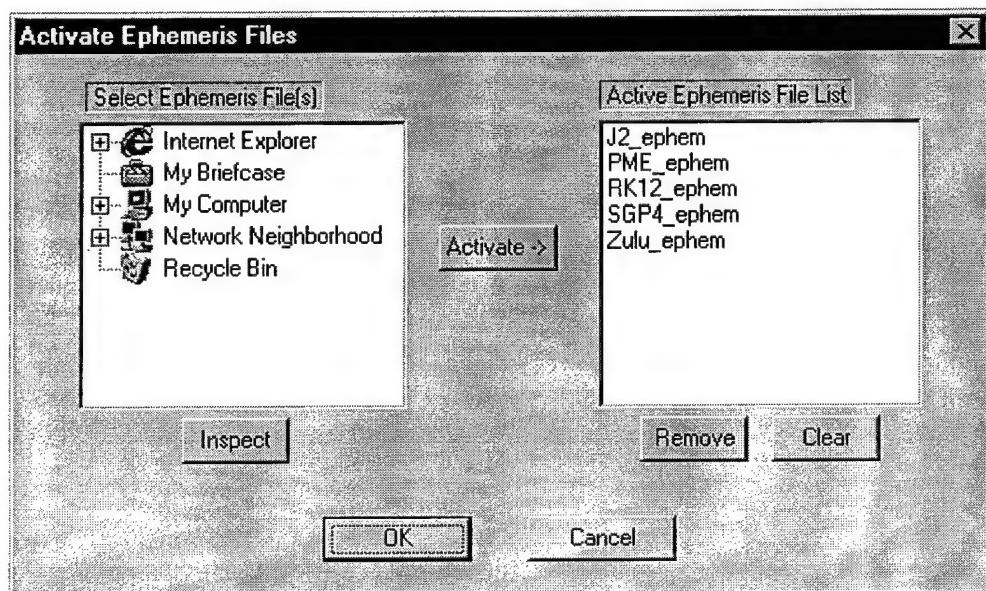


Figure 4.2. Activate Ephemeris Files dialog

Any text file can be selected from the directory tree and sent to the active ephemeris file list by clicking on the *Activate* button regardless of whether or not the file has a valid ephemeris format. An invalid file will not cause an error here, but the user is alerted if he/she attempts to use the file for plotting or analysis. As a preventative measure, the user can elect to view the contents of a selected file prior to activating it by clicking on the *Inspect* button. This brings up the dialog shown in Figure 4.3.

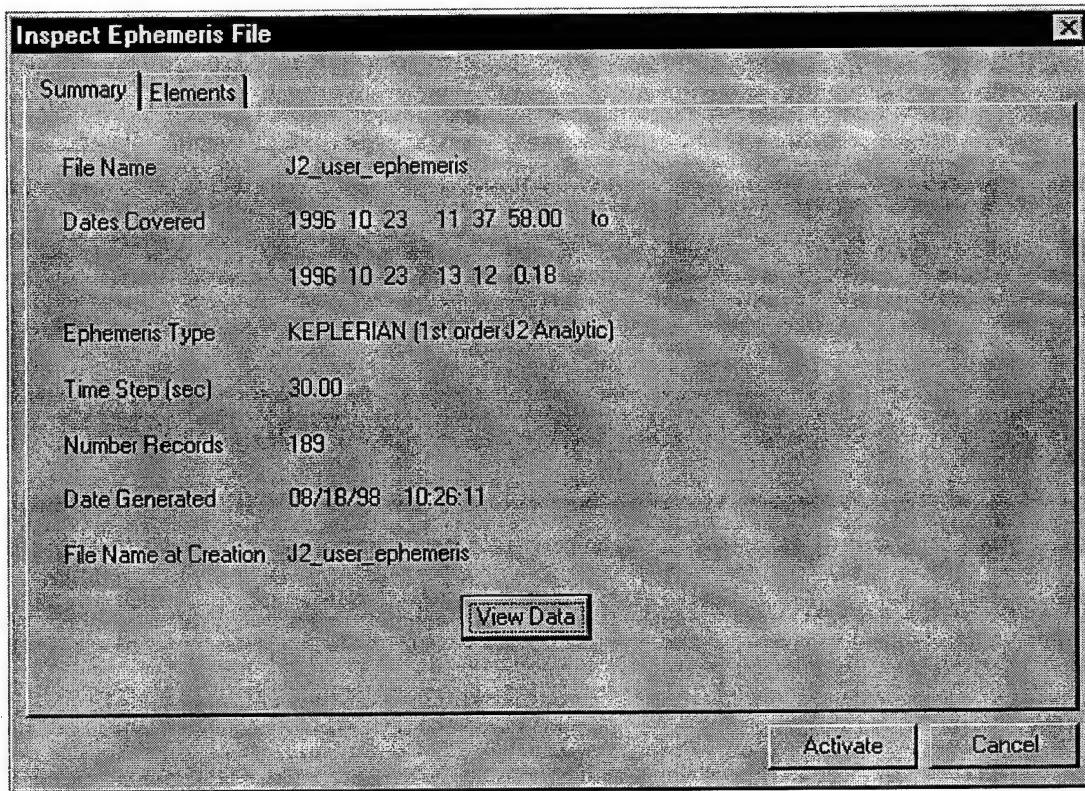


Figure 4.3. *Inspect Ephemeris File* dialog

The *Summary* page of this tabbed dialog displays information contained in the header of any OATS-generated ephemeris file. If the inspected file is either not OATS-generated or not an ephemeris file at all, the user is alerted and the fields in the *Inspect Ephemeris File* dialog will be blank. The contents of the file can be directly viewed by clicking on the *View Data* button — a *Text Window* as seen in Figure 2.3 will display the file. The orbital elements of a valid, OATS-generated ephemeris file can be seen by clicking on the *Elements* tab. A read-only version of the *Elements* page of the *Generate Ephemeris* dialog is displayed with all fields filled in using the data from the file header.

After complete inspection, the user can add this file to the active list by clicking on the *Activate* button at the bottom-right of the dialog. Clicking on *Cancel* will return the user back to the *Activate Ephemeris Files* dialog.

Multiple files can be selected from the directory tree and activated simultaneously. One method of doing this is to click on a text file name, hold down the Shift key, then click on another text file within the same directory. This will select the entire range of files between the two clicked-on files. To select multiple files in different directories, hold down the Ctrl key while selecting the different files with the mouse. Clicking on the *Activate* button will add all selected files to the active list. Note that if multiple files are selected, clicking on the *Inspect* button will only display the top-most selected file in the *Inspect Ephemeris File* dialog. In a similar fashion, single or multiple file names can be removed from the active ephemeris file list by clicking on *Remove* following selection. All file names are removed if the *Clear* button is pressed. Any changes made to the active file list will be saved only upon exiting the *Activate Ephemeris Files* dialog via the *OK* button.

4.2 Position Check

This option provides a calculation of a satellite's position accurately interpolated from the satellite ephemeris file. For any active ephemeris file, the interface shown in Figure 4.4 provides a means of computing the satellite position within the temporal bounds of that file. The time span of a selected file is displayed, and the user may enter a time in the appropriate fields within that time span. Upon clicking the *Show Position* button, the latitude, longitude, altitude, and hour angle of the satellite are computed for the user-entered time point and displayed at the bottom of the dialog. This can be repeated as often as desired for as many files as desired. The *Close* button exits the dialog.

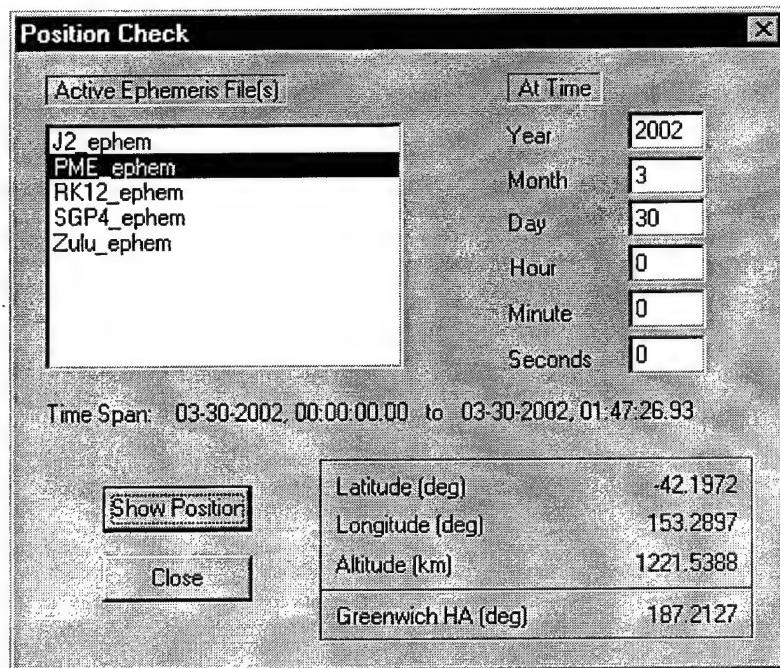


Figure 4.4. Position Check dialog

4.3 Attitude File Activation

The *Files...* option in the *Attitude* menu (Figure 4.1) functions in nearly the same manner as the same option for ephemeris files. The only difference is when the *View Data* button is clicked for a selected text file in the *Attitude Files* dialog, a text window appears displaying the contents of the file instead of the interface shown in Figure 4.3. There is no one-to-one correspondence between attitude files and ephemeris files, but associations can be made by the user when setting attitude parameters for the satellite swath or FOV plotting functions (Sections 6.3 and 6.5) or when setting tabular coverage constraints (Section 5.3).

4.4 Pointing Check

This option provides a calculation of satellite pointing accurately interpolated from the satellite attitude file. For any active attitude file, the interface shown in Figure 4.5 provides a means of computing the satellite attitude within the temporal bounds of that file. The time span of a selected file is displayed, and the user may enter a time in the appropriate fields within that time span. Upon clicking the *Show Angles* button, the angles are computed for the user-entered time point and displayed at the bottom of the dialog. The types of angles shown are dependent on the format of the file (see Section 8.8). This process can be repeated as often as desired for as many files as desired. The *Close* button exits the dialog.

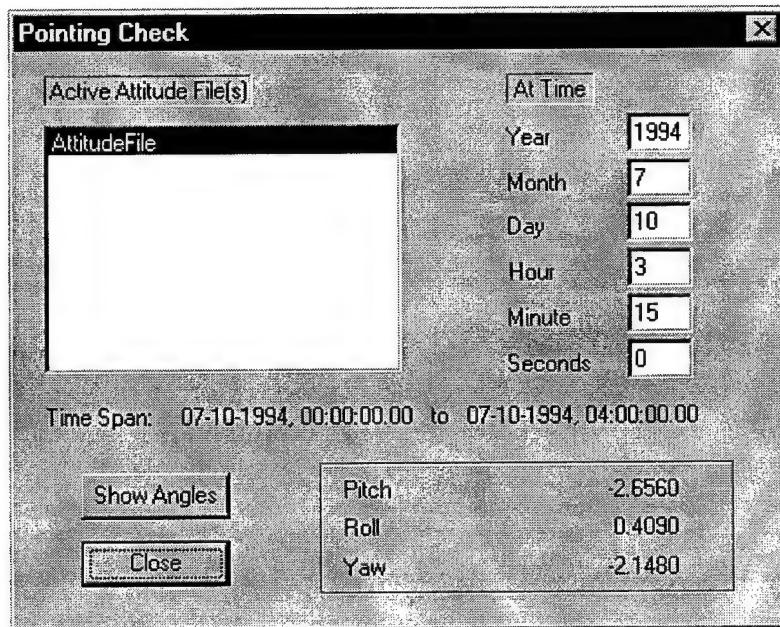


Figure 4.5. Pointing Check dialog

Chapter 5

Coverage

OATS has the ability to perform three types of orbit coverage analysis — tabular coverage, graphical coverage, and look angle coverage. These three computational options as well as coverage comparison functions can be accessed either by the *Coverage* menu or the corresponding toolbar.

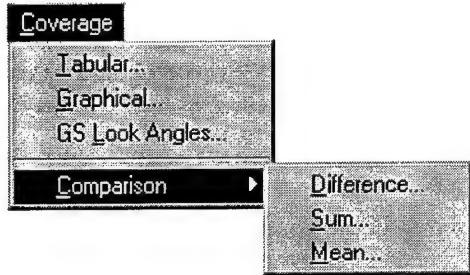


Figure 5.1. Coverage menu

In the following sections, ground station visibility is defined to occur when the satellite is above some minimum elevation from the ground station horizon. Target visibility is defined to occur when the target lies in the satellite antenna pattern.

5.1 Antenna Parameters

Spacecraft antenna parameters can be set for each ephemeris file in the tabular and graphical coverage dialogs as well as the dialogs for plotting satellite field-of-view, satellite swath, and snapshot (see Chapter 6). Clicking on the *Set Antenna Parameters* button in any of these dialogs brings up the dialog seen in Figure 5.2.

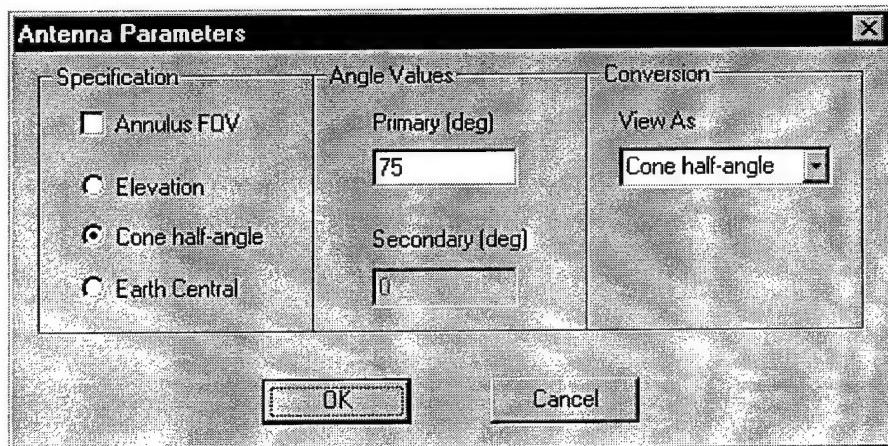


Figure 5.2. Antenna Parameters dialog

The angles specification is selected using the radio buttons on the left side of the dialog for the angle type and a checkbox for selecting a FOV shaped like an annulus. Angle values for the antenna may be specified in the center section of the dialog — the *Secondary* angle is only required if *Annulus FOV* is checked. The right section of the dialog contains a drop-down list from which the user can convert to a different angle specification. The angle(s) for the antenna are then computed in an alternate geometry and displayed in the center section of the dialog.

5.2 Attitude Parameters

Similar to antenna parameters, attitude parameters are optionally set for each ephemeris file in the tabular and graphical coverage dialogs and the dialogs for plotting satellite field-of-view, satellite swath, and snapshot (see Chapter 6). Clicking on the *Set Attitude Parameters* button in any of these dialogs brings up the dialog seen in Figure 5.3.

Attitude parameters can be set either by entering in fixed values or by using values from a file. If the *Use Fixed Values* button is selected, the *Attitude Type* may be specified as either *Pitch/Roll/Yaw*, *Intertial Stare*, or *Orbit Fixed with respect to Perigee*. The precise definitions of these attitude specifications may be found in Appendix A.

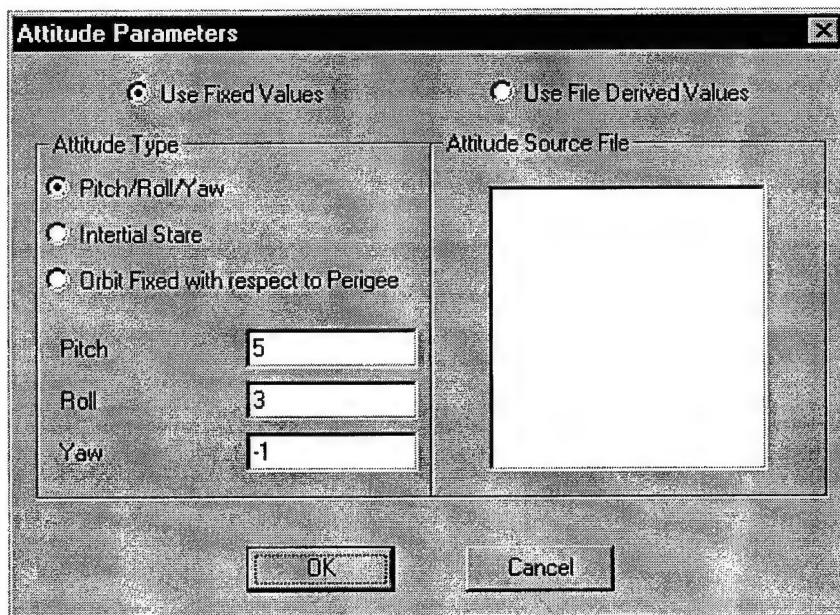


Figure 5.3. Attitude Parameters Dialog

If *Use File Derived Values* is selected, an attitude file must then be selected in the list box on the right side of the dialog. This list box displays only those files that have been previously activated (see Section 4.3).

5.3 Tabular Coverage

This analytical procedure yields a tabulated list of visibility statistics for a user-defined combination of ground stations, satellites, and targets. Up to 31 ground stations, 27 satellites (synonymous with a maximum 27 active ephemeris files), and 100 targets may be used in a single run. The tabular coverage function computes orbital coverage statistics for a system of satellites as viewed by a set of ground targets. A target is covered when exactly n satellites or n -or-more satellites in the system are visible to the target. Any or all of the satellites may optionally have a constraint applied such that any or all of a set of ground stations must be visible for coverage to exist. This is a condition that might apply if a direct satellite communications link is required. The antenna pattern is specified for each satellite individually. The tabular coverage function uses an oblate Earth and can optionally account for atmospheric refraction effects.

Six sets of data required for the tabular coverage run can be set in the dialog launched by selecting *Tabular...* from the *Coverage* menu or by clicking on the *Tabular Coverage* toolbar button. These data include at least one ephemeris file, optional antenna parameters for each file, optional attitude parameters for each file, optional ground stations, at least one target position, and the time interval.

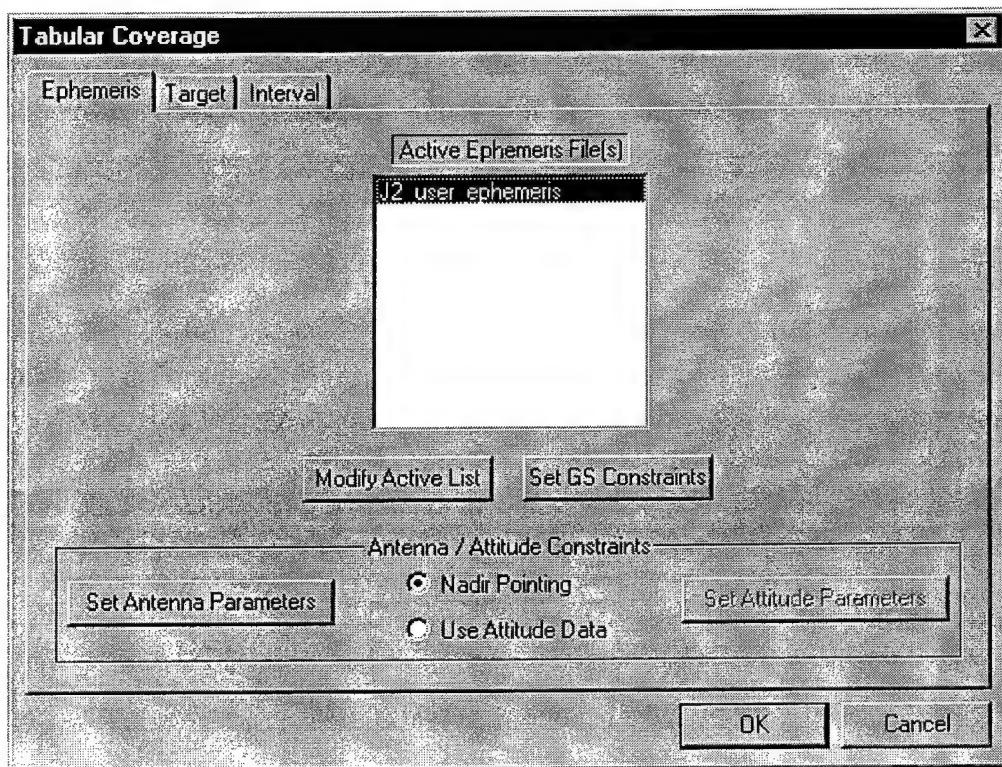


Figure 5.4. Tabular Coverage dialog, Ephemeris page

A majority of the required data is set in the first tabbed page of this dialog, titled *Ephemeris*. The ephemeris files to be used for the tabular coverage run are listed at the

top of this page. Clicking on the *Modify Active List* button brings up the *Activate Ephemeris Files* dialog seen in Figure 4.2 from which the user may activate or deactivate files. Ground station constraints can be set for each ephemeris file by selecting the file in the list and clicking on the *Set GS Constraints* button. This brings up the dialog shown in Figure 5.5 in which the user can select a subset of ground stations from the active list and move them to the validated list to be used in the coverage run. The radio buttons on the right side of the dialog permit a choice of *ANY* or *ALL* of the validated ground stations are visible as a constraining condition. The *Clear* button removes all of the ground stations in the validated list. The user can alter the active ground station list by clicking on the *Modify Active List* button, which brings up the *Ground Stations* dialog seen in Figure 5.6. Within that dialog, the user can activate and deactivate ground stations, open a ground station list from a file, save the ground station list to a file, view a ground station's information by selecting it, and add a ground station to the list by entering the information on the right hand side and clicking *Add* (see Section 6.7). Clicking on *OK* will return the user to the *Ground Station Constraints* dialog with the newly modified active ground station list displayed.

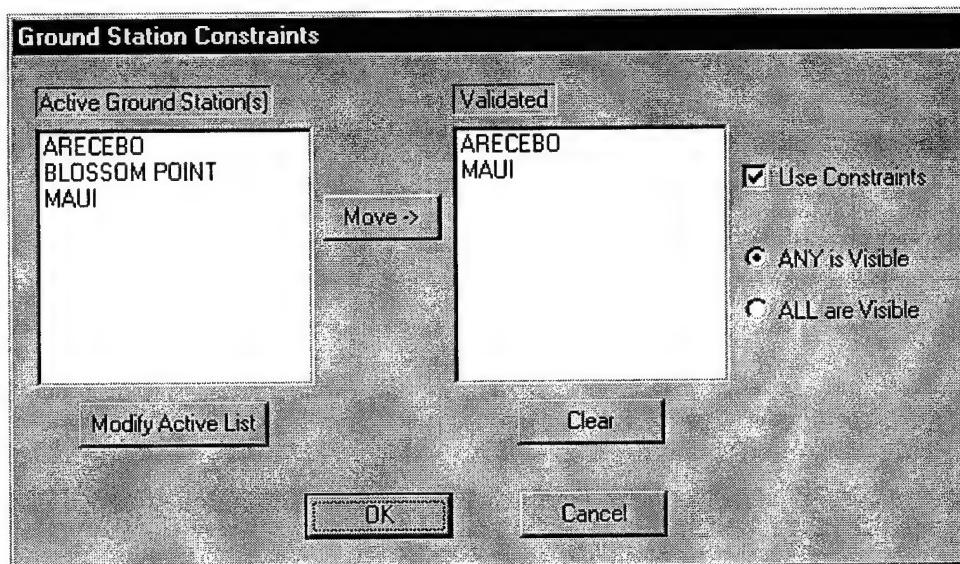


Figure 5.5. *Ground Station Constraints* dialog

The antenna and attitude parameters for the selected ephemeris file can be specified by clicking the respective *Set Antenna Parameters* and *Set Attitude Parameters* buttons and following the procedures described in Sections 5.1 and 5.2. The *Set Attitude Parameters* button is only active if the radio button for *Use Attitude Data* in the center of the *Ephemeris* page is selected.

The second tab of the *Tabular Coverage* dialog brings forward the *Target* page. A list of active targets to be used in the coverage run is displayed on the left side, and this list can be altered in the same fashion as the active ground station list. The constraining

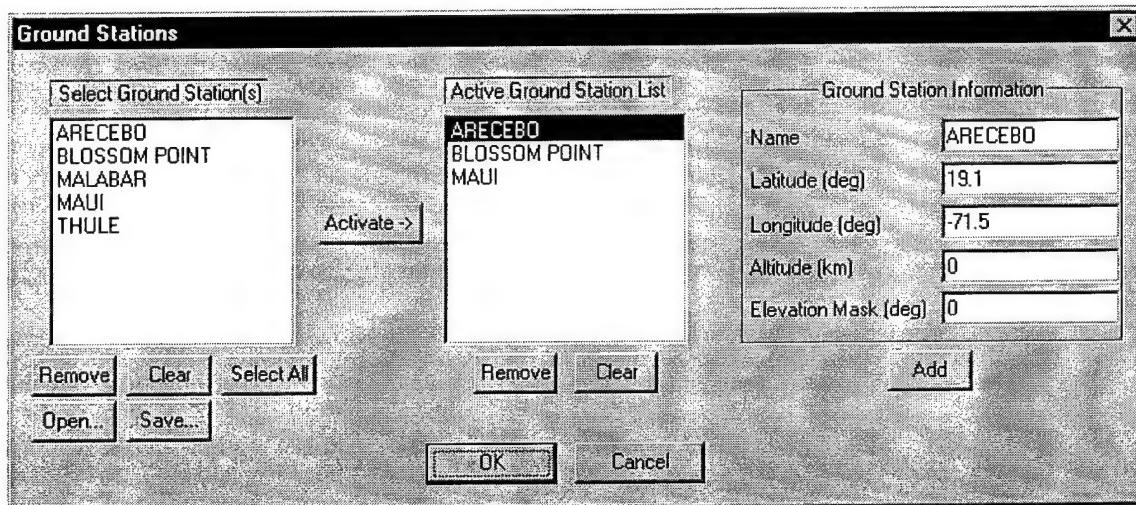


Figure 5.6. Ground Stations dialog

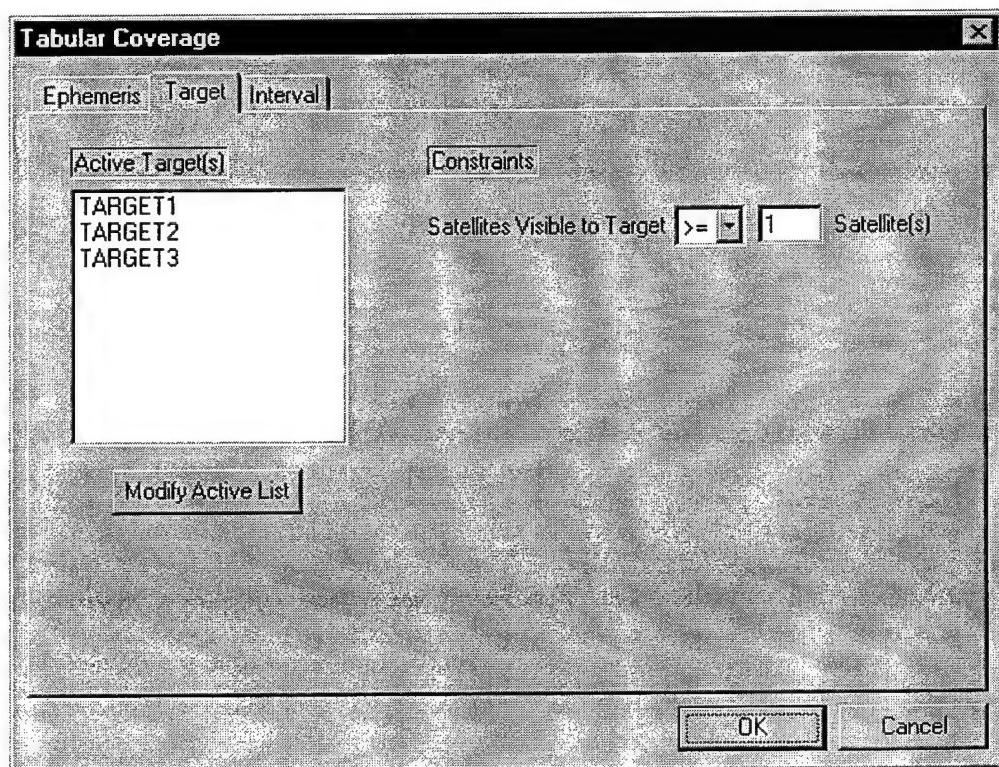


Figure 5.7. Tabular Coverage dialog, Target page

condition of $=$ or $\geq n$ satellites, where n is the user-entered number of visible satellites, is set to the right of the active target list. The target visibility by individual satellites is determined by nesting their ground station constraints (if any) simultaneously with the target lying in the antenna pattern.

Clicking on the third tab of the *Tabular Coverage* dialog brings the *Interval* page to the foreground, as shown in Figure 5.8. The start and stop times of the interval are automatically set to the respective minimum and maximum values of the start and stop times of the ephemeris files in the active list. These values may be changed, but they must lie within the bounds of the ephemeris files used. The step size is used to set the output computational interval which has no direct relationship with the intervals used when creating ephemeris files. The user can choose the options to *Print Up/Down Times* for each coverage period and to use *Atmospheric Refraction Correction*.

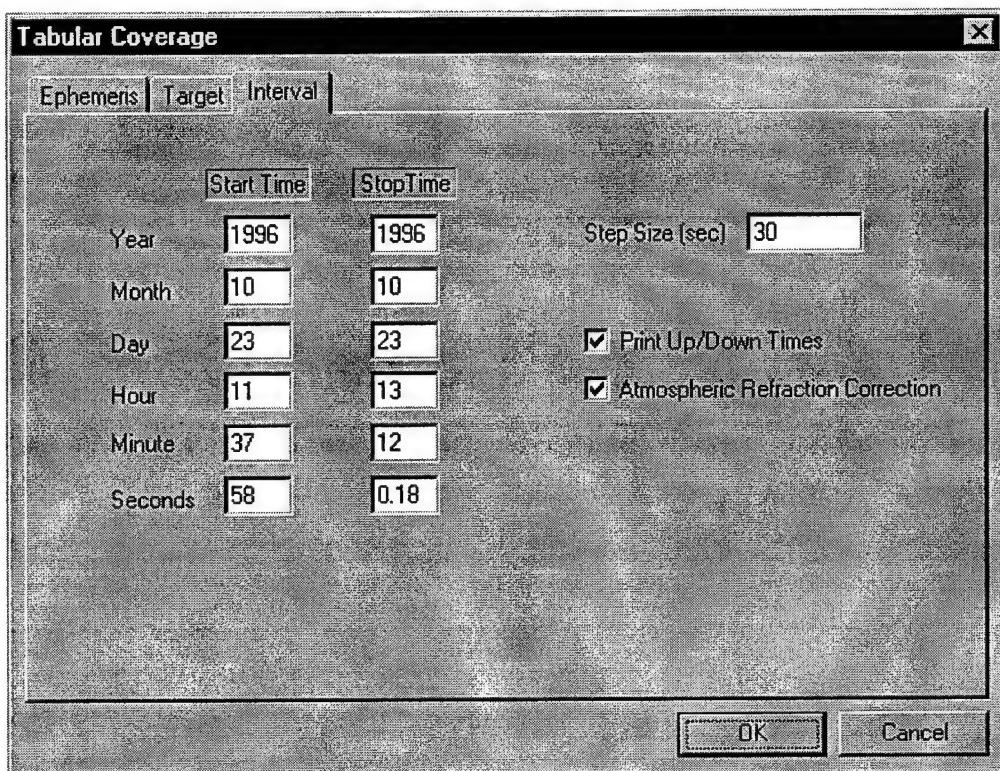


Figure 5.8. *Tabular Coverage* dialog, *Interval* page

After all data have been entered, click the *OK* button at the bottom of the dialog to initiate calculation of the tabular coverage. Clicking on the *Cancel* button will close the dialog without executing the coverage run. After clicking on *OK*, a dialog will appear in which the user may specify the directory and filename of the tabular file about to be generated. Exiting this dialog with an *OK* will initiate the run and write the results to the specified file. If the *Cancel* button is pressed, the data is still preserved but no tabular coverage file is created. If the echo on-screen parameter for tabular coverage computations was previously selected in the *OATS Parameters* dialog (see Section 2.9), a text window will appear (if not already visible) to display the ephemeris data as it is simultaneously being written to the file.

5.4 Graphical Coverage

The graphical coverage function computes world-wide coverage of a system of satellites. This process computes the cumulative coverage, average outage, and maximum outage times over a global target grid uniformly spaced in latitude and longitude. Target visibility is defined to occur when one or more satellites has the target in its antenna pattern while its ground station constraint (if any) is simultaneously satisfied. The process does not employ n-fold coverage as in the tabular case. The meridian mesh technique of Casten and Gross (Reference 7) is used for nadir pointing satellite, and a related meridian mesh technique from Middour (Reference 8) is used for attitude-dependent cases. Coverage statistics are computed at each point in the grid. The technique is quick due to the use of a spherical earth as a simplifying assumption for the target positions, although an oblate earth model is used for the ground station constraints. Coverage is calculated using geometry only — no atmospheric or aberration effects are included in the model.

By itself, this analysis function does not produce coverage information that is of direct value to most users. However, it serves as a set-up procedure that yields a single file of tabulated coverage data that can be employed by the *Plot* menu options (see Sections 6.9 and 6.10) to produce a graphic contour or density mapping of satellite coverage. This mapping is shown superimposed on an earth plot to show the extent of coverage for a given satellite grouping. The user can specify both dimensions of the global latitude and longitude mesh size. An increment as small as 1.0 degree can be used. However, the smaller the mesh size the longer the compute time. The mesh effectively takes the place of the individual targets used in the tabular coverage procedures discussed before. As with tabular coverage, any or all of the satellites may optionally have a constraint applied such that at least one ground station must be visible for coverage to exist. Up to 31 ground stations and 27 satellite ephemeris files may also be used as simultaneous inputs to the graphical coverage analysis.

Six sets of data are required for the graphical coverage run. These include at least one ephemeris file, optional antenna parameters for each file, optional attitude parameters for each file, optional ground stations, the latitude and longitude spacing of the global mesh elements, and the time interval. A majority of the required data is set in the dialog launched by selecting *Graphical...* from the *Coverage* menu or by clicking on the *Graphical Coverage* toolbar button. The *Ephemeris* page of this dialog seen in Figure 5.9 functions in exactly the same way as in the *Tabular Coverage* dialog (see Section 5.3). The *Interval* page of the dialog (Figure 5.10) is also similar to that of the *Tabular Coverage* in the selection of start / stop times and step size. However, on this *Interval* page there is an option for the user to use data compression in order to save disk space. A discussion of compression and how the data in the output file is mapped onto the global grid is provided in Section 8.7.

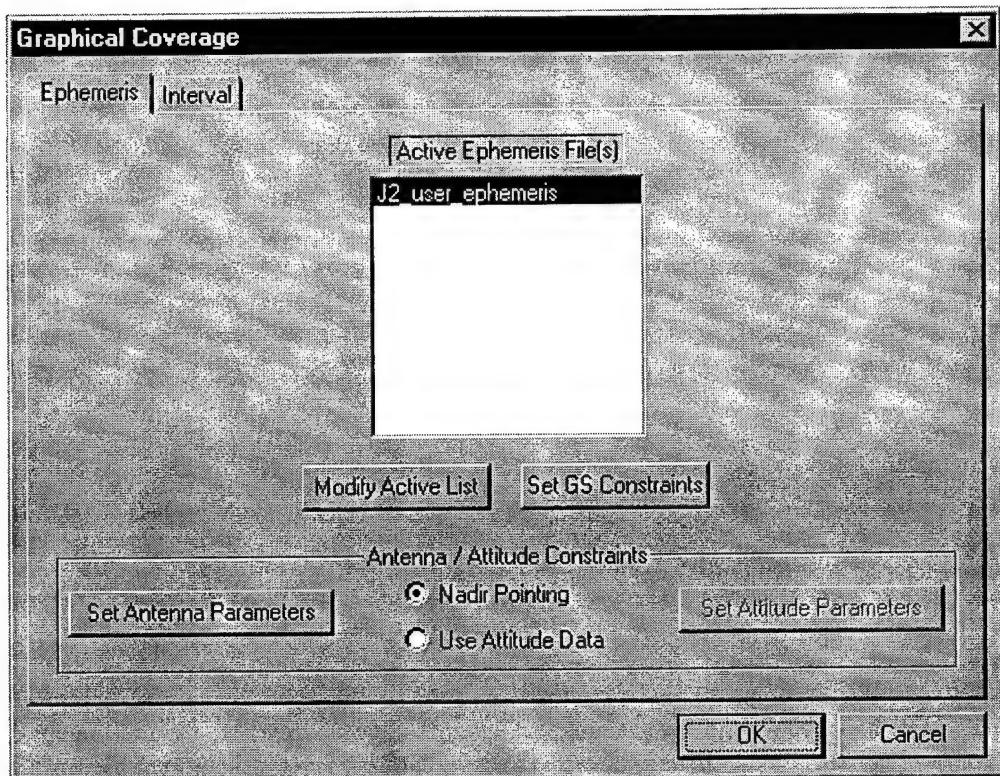


Figure 5.9. Graphical Coverage dialog, Ephemeris page

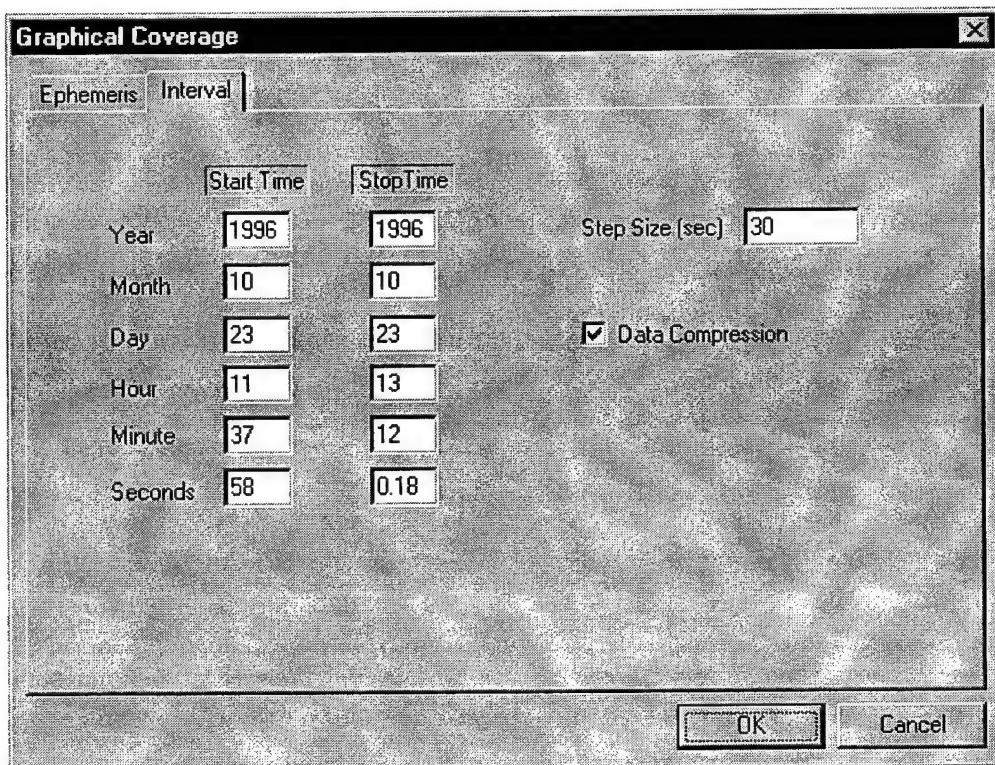


Figure 5.10. Graphical Coverage dialog, Interval page

After all data have been entered in the *Graphical Coverage* dialog, click the *OK* button at the bottom of the dialog to initiate calculation of the tabular coverage. Clicking on the *Cancel* button will close the dialog without executing the coverage run. After clicking on *OK*, the dialog shown in Figure 5.11 will appear in which the user must set the latitude and longitude spacing of the global mesh elements. Mesh dimensions must be entered as integer values greater than or equal to 1 degree.

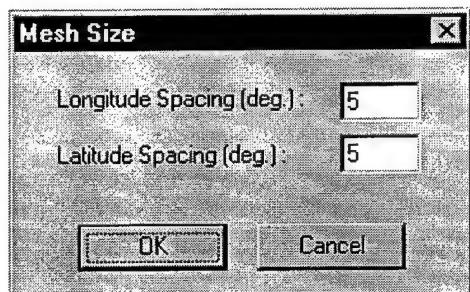


Figure 5.11. Mesh Size dialog

After exiting the *Mesh Size* dialog by clicking *OK*, the user can specify the directory and filename of the coverage file to be generated in a file selection dialog. If the *Cancel* button is pressed, the data from the *Graphical Coverage* dialog is preserved but no coverage file is created. If the echo on-screen parameter for graphical coverage computations was previously selected in the *OATS Parameters* dialog (see Section 2.9), a text window will appear (if not already visible) to display the data as it is simultaneously being written to the file. Upon completion of the generation of the coverage file, a summary of the data it contains is displayed if the user so chose in the *OATS Parameters* dialog. An example of a graphical coverage summary is shown in Figure 5.12. This display requires no user inputs — it exists only to give the user some concept of the values that should be employed in the contour plotting options (see Sections 6.9 and 6.10).

	Percentage of Time	Average Daily Coverage	Total Cumulative Coverage	Average Outage	Maximum Outage
Maximum	11.7	168.45	11	94.5	94.5
Minimum	0	0	0	83.5	6.5
Mean	0.62	8.82	0.58	93.93	89.16
Longitude Mesh Size (deg)	5		Latitude Mesh Size (deg)	5	
				OK	

Figure 5.12. Graphical Coverage Summary dialog

5.5 Look Angle Coverage

Look angle coverage is used to produce a tabular list of data that describe where and when a single ground station will be able to view a single satellite as it passes overhead. The listing includes readouts of time versus azimuth, elevation, range, range rate information, shadow status, and signal attenuation. Calculations for the look angles solutions use an oblate earth, atmospheric refraction, aberration, and a Hopfield model for the tropospheric refraction effect on signal transmission through the earth's atmosphere (Reference 9).

Four pieces of data are required in order to execute a look angles coverage run. These include a single ground station, a single satellite ephemeris, optional up-link and down-link communication frequencies, and the time interval. All of this information may be entered in the dialog launched by selecting *GS Look Angles...* from the *Coverage* menu or by clicking on the corresponding toolbar button.

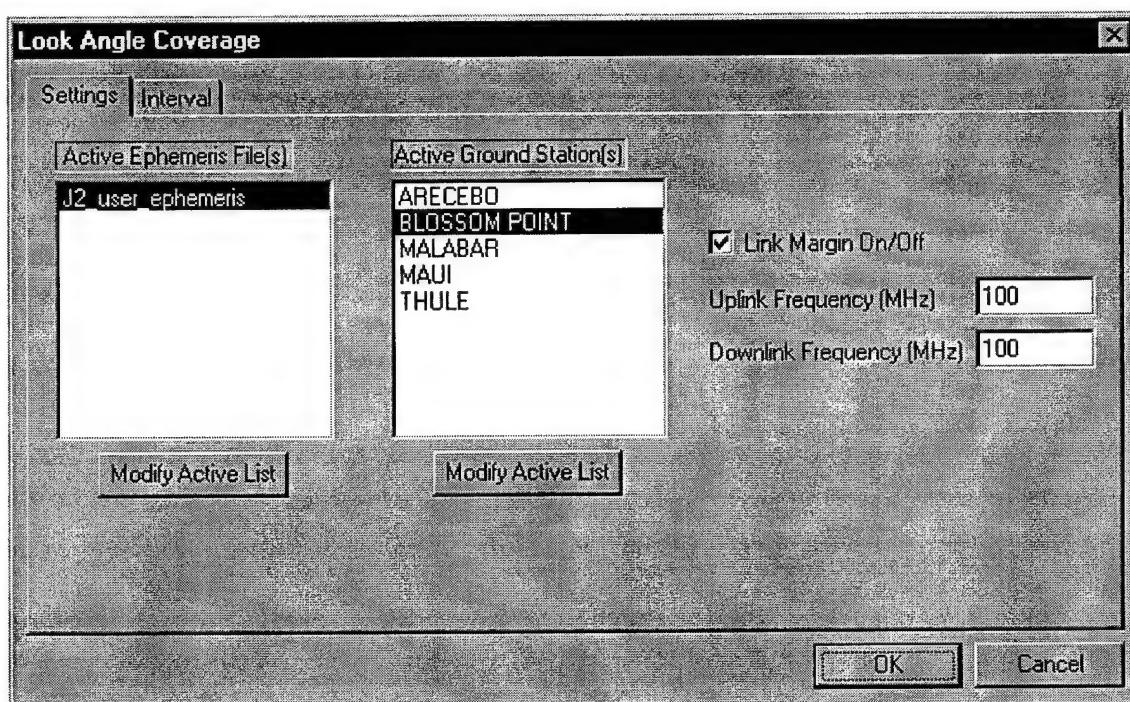


Figure 5.13. Look Angle Coverage dialog, Settings Page

In the *Settings* page of the dialog, as seen in Figure 5.13, the user selects the ephemeris file and ground station to be used for the coverage run by clicking on the desired choices in their respective active lists. Clicking the *Modify Active List* button located below the ephemeris file list brings up the *Activate Ephemeris Files* dialog seen in Figure 4.2 from which the user may activate or deactivate files. The ground station list can be similarly altered by clicking on its corresponding *Modify Active List* button and making the desired modifications in the *Ground Stations* dialog as seen in Figure 5.6. The user can also choose whether or not to use link margin computations from this portion of the dialog.

The up-link and down-link frequencies (in megahertz) are used to compute signal attenuation. The mathematical formulation of the link margin computations can be found in Reference 10.

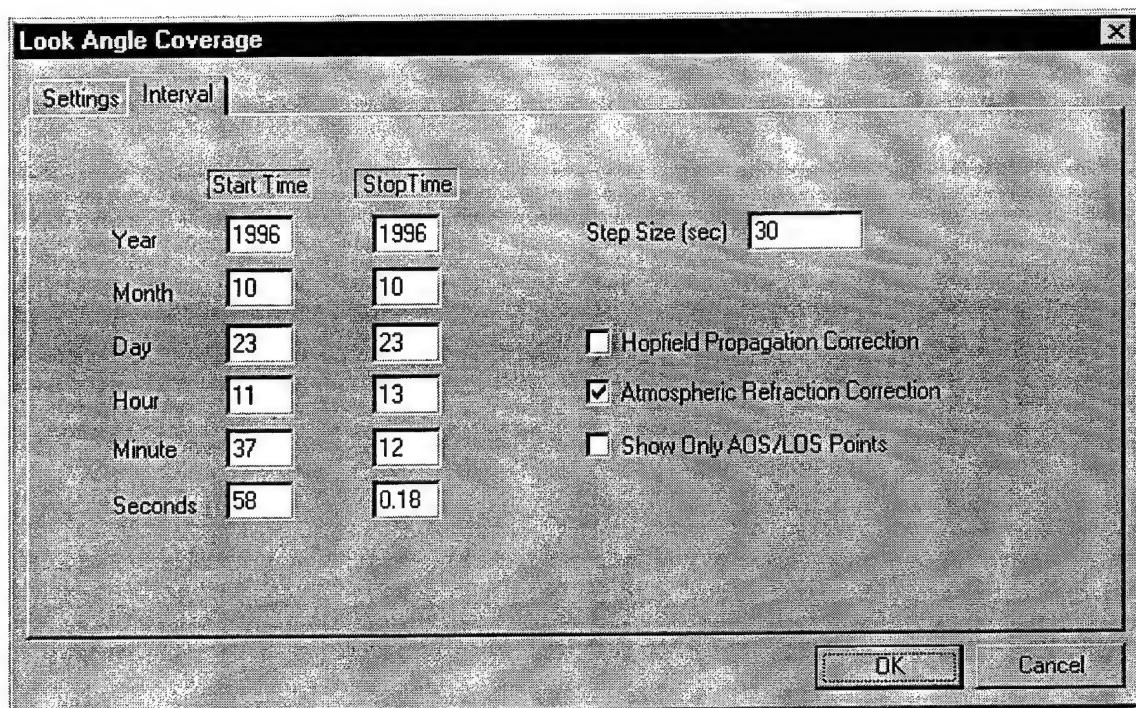


Figure 5.14. Look Angle Coverage dialog, Interval page

On the *Interval* page of the *Look Angle Coverage* dialog the start and stop times of the interval are automatically set to the start and stop times of the ephemeris file that is selected on the *Settings* page. These values may be changed, but they must lie within the bounds of the chosen ephemeris file. The step size is used to set the computational interval which has no direct relationship with the interval used when creating the ephemeris file. The user can choose any of the checkbox options for *Hopfield Propagation Correction*, *Atmospheric Refraction Correction*, and *Show Only AOS/LOS Points* to be used in the coverage run.

After all data have been entered, click the *OK* button at the bottom of the dialog to initiate calculation of the look angle coverage. Clicking on the *Cancel* button will close the dialog without executing the coverage run. After clicking on *OK*, a dialog will appear in which the user may specify the directory and filename of the file about to be generated. Exiting this dialog with an *OK* will initiate the run and write the results to the specified file. If the *Cancel* button is pressed, the data is still preserved but no coverage file is created. If the echo on-screen parameter for look angle computations was previously selected in the *OATS Parameters* dialog (see Section 2.9), a text window will appear (if not already visible) to display the data as it is simultaneously being written to the file.

5.6 Coverage Comparison

Comparisons between graphical coverage files are, in effect, a limited special-purpose type of image processing. It is possible in OATS to perform the difference between two graphical coverage files, the sum of two files, or the mean of multiple files. Prior to running any of these comparisons, it is necessary that the graphical coverage files already be generated using the same size coordinate mesh.

Upon selecting *Difference...* from the *Comparison* submenu (see Figure 5.1) or clicking the corresponding toolbar button, a dialog such as that seen in Figure 5.15 appears. The user can click on any text file in the directory tree in the left side of the dialog and then designate it as either the base or comparison file by clicking on the appropriate arrow button. The option for data compression also exists in the dialog. Upon clicking the *OK* button, a dialog will appear in which the user may specify the directory and filename of the comparison file about to be generated. Exiting that dialog with an *OK* will initiate the comparison run and write the results (*base - comparison*) to the specified file. If the echo on-screen parameter for graphical coverage difference values was previously selected in the *OATS Parameters* dialog (see Section 2.9), a text window will appear (if not already visible) to display the data as it is simultaneously being written to the file.

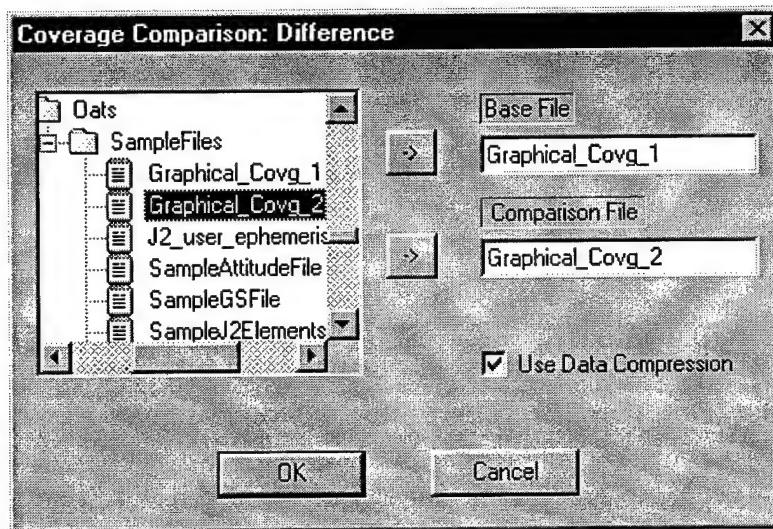


Figure 5.15. Difference Coverage Comparison dialog

The procedure for executing the sum of two graphical coverage files (*base + comparison*) is identical to that of the difference comparison.

In computing the mean of graphical coverage files, two or more files can be selected. The dialog launched by selecting *Mean...* from the *Comparison* submenu or by clicking the appropriate toolbar button is shown in Figure 5.16. Multiple files may be selected in the directory tree in the left side of the dialog and designated for use in the comparison by clicking on the arrow button. Any files that are mistakenly placed in the selected files list can be removed from the list by clicking on the file name(s) and then clicking the *Remove*

button. The *Clear* button erases all files in the selected list. Clicking the *OK* button launches the dialog in which the user may specify the directory and filename of the comparison file about to be generated. Exiting that dialog with an *OK* will initiate the comparison run and write the results to the specified file. If the echo on-screen parameter for graphical coverage mean values was previously selected in the *OATS Parameters* dialog (see Section 2.9), the data is displayed in a text window as it is simultaneously being written to the file.

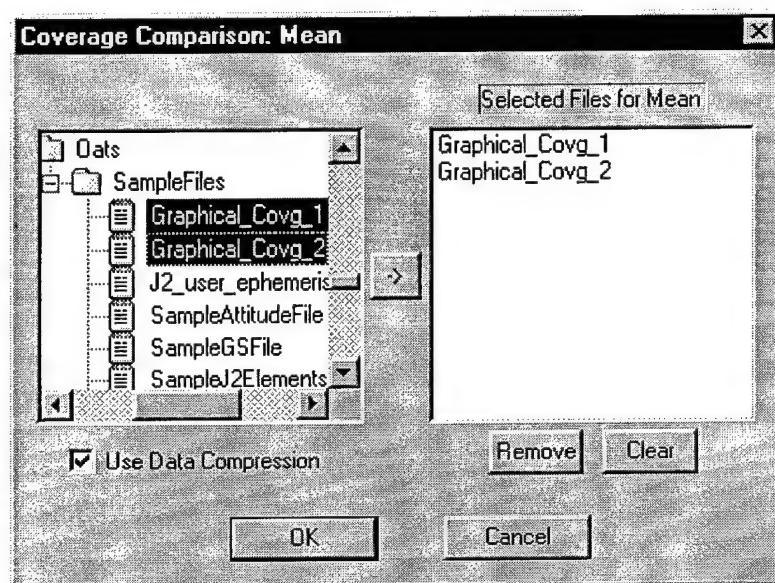


Figure 5.16. Mean Coverage Comparison dialog

Chapter 6

Graphics

All of the OATS plot functions are defined through the *Plot* menu choices as seen in Figure 6.1. Because graphical displays of satellite coverage and coverage related phenomena are the primary thrust for the development of OATS, this menu is quite important and has many options.

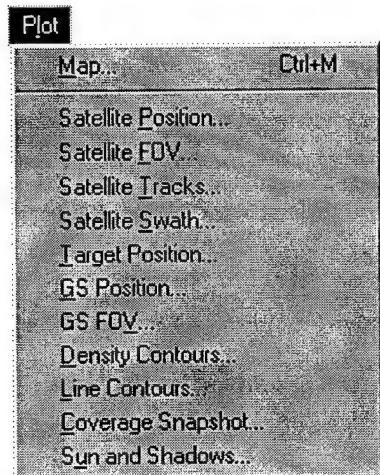


Figure 6.1. *Plot* menu

6.1 Maps

Plotting maps is an important part of OATS, since a global map forms the background against which all other graphics are plotted. The *Plot Map* dialog, launched by either selecting *Map...* from the *Plot* menu, by clicking on the associated toolbar button, or by typing the accelerator *Ctrl+M*, contains three tabbed pages in which the user can specify all parameters for a customized map: *Projection*, *Grid*, and *Options*.

A map projection is the systematic mathematically defined representation of all or part of the surface of a three-dimensional spherical body (the earth) on a two-dimensional surface (the computer screen). All map projections will produce some level of distortion of map features with the distortion occurring in map characteristics like area, shape, or scale. The map projection employed is usually selected based upon which distortion it is most critical to minimize. Various presentations of the *Projection* page of the *Plot Map* dialog are shown (reduced size) in Figure 6.2 to demonstrate the different defining parameters for the six map projections available in OATS. Each of the six map projections (seen in Figure 6.3) can be selected via the radio button next to its name, which will show a view of input parameters appropriate to that map projection. Note that the dialog page has the same appearance for the *Rectangular*, *Mercator*, and *Equal Area* selections.

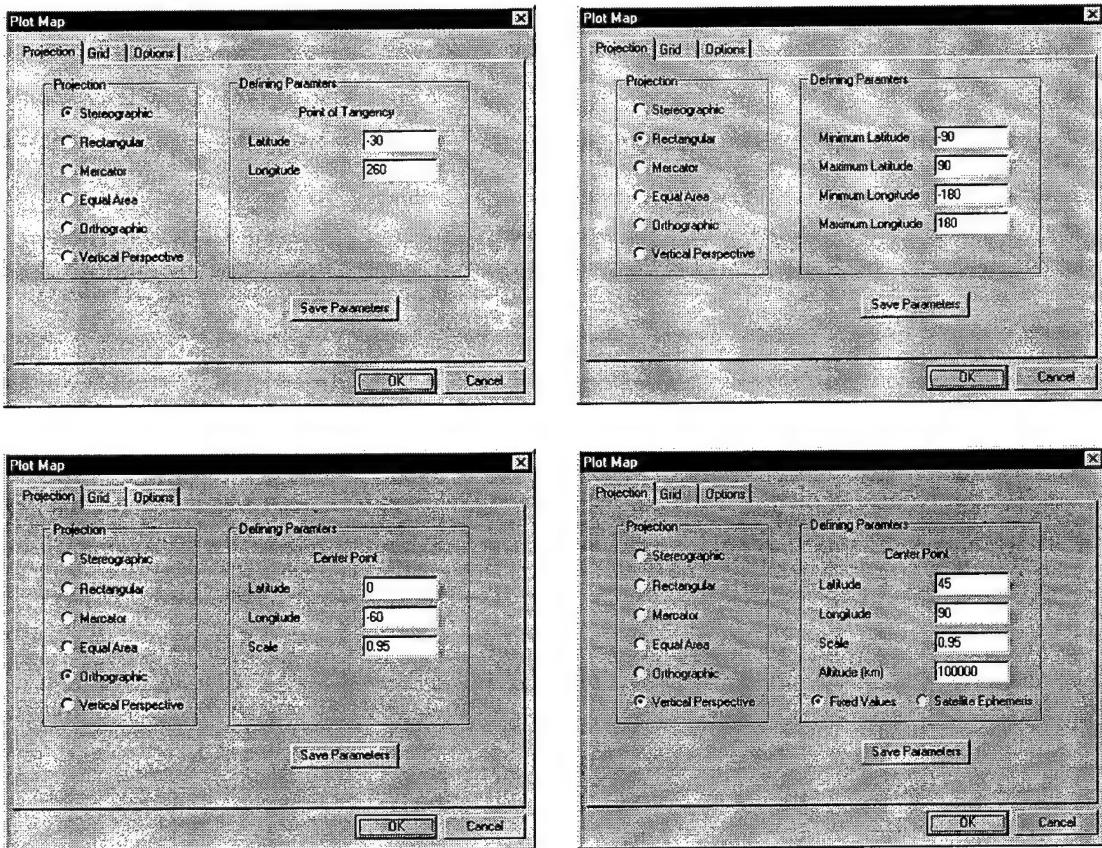
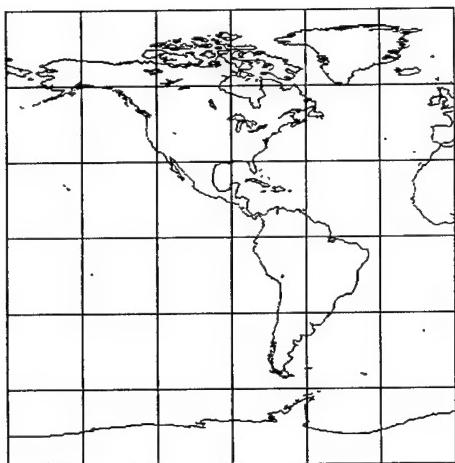
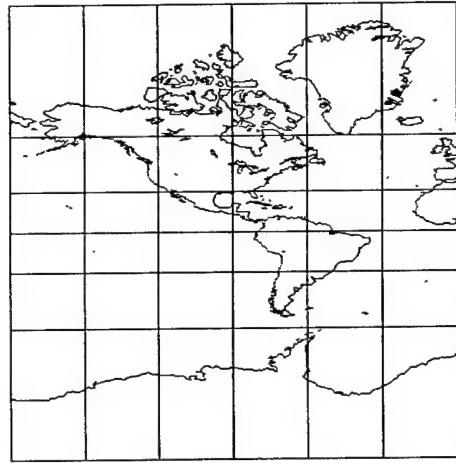


Figure 6.2. Plot Map dialog, Projection page variations

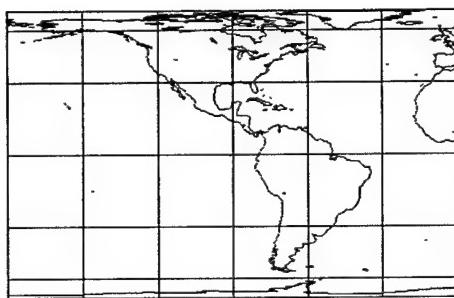
- **Rectangular** — This projection is the first of three OATS cylindrical projections, so named because it is from a family of transformations formed by projecting the earth's surface onto a cylinder wrapped around the sphere at the Equator. Such a map projection has a conceptual cut along which the projection-cylinder is cut and then unrolled onto the flat surface. The Rectangular Projection (also known as Equidistant Cylindrical) makes no attempt to minimize any map distortion. However, it is the simplest map projection to construct and understand because latitude and longitude are presented as equally scaled Cartesian coordinates. The minimum and maximum latitude and longitude are required to define this projection. All cylindrical longitudes should fall between -360 and +360 and should not exceed a total range of 360 degrees. Rectangular minimum latitude should be at least -90 degrees, and maximum latitude should not exceed +90 degrees.
- **Mercator** — The Mercator projection is another cylindrical map projection that preserves map scale near the Equator. Two major drawbacks of this projection are the significant area distortion near the poles and the poles themselves are an infinite distance from the Equator due to vertical distance being scaled according to the secant of latitude. Thus, the minimum latitude must be greater than -90 degrees and the maximum latitude less than +90 degrees.



Rectangular



Mercator



Equal Area



Stereographic



Orthographic



Vertical Perspective

Figure 6.3. Sample views of available OATS map projections

- *Equal Area* — This is the third cylindrical map projection, also known as the Lambert Cylindrical Equal-Area projection. Area size of map features is preserved by making a perspective projection of the earth sphere onto the encircling projection-cylinder using the sine of the latitude. The major drawback of this projection is the extreme shape and scale distortion near the poles. Longitude and latitude bounds are the same as those for the Rectangular map projection.
- *Stereographic* — This map projection presents a view of the sphere projected onto a plane tangent to (one point touching) the sphere. It preserves the shape of map features (conformal) and relative directions at any given point (azimuthal). Its major drawbacks are the area and scale distortions near the edges. The point of tangency in latitude and longitude is required to define this projection.
- *Orthographic* — The orthographic map projection is equivalent to a perspective projection viewed from an infinite distance. Zero distortion exists only at the center, and significant distortion occurs near the edge of the visible hemisphere. This projection is useful because it resembles the earth from a perspective view while maximizing the visible surface. It provides a very reasonable approximation to a three-dimensional view of the sphere and can be used effectively for showing the space track of a satellite. The latitude and longitude of the center point of the view (the tangent point of the projection plane) is required as well as a scale factor to determine the size of the spherical plot. The scale factor should be greater than 0 and no larger than 1.
- *Vertical Perspective* — This map projection mimics the view of the earth as seen from a nadir pointing satellite in orbit. Distortion is minimized at the center only and grows as the edge is approached. The user may select whether the viewing point comes from *Fixed Values* of latitude, longitude, and altitude, or from a *Satellite Ephemeris*. If *Satellite Ephemeris* is selected, an additional dialog will appear after closing the *Plot Map* dialog with *OK* in which the view point is selected as any point within any active ephemeris file.

When the dialog is exited with an *OK*, the defining map parameters for the selected map projection are saved. If the user wishes to save more than one set of parameters during a single viewing of this dialog, clicking the *Save Parameters* button will do just that without exiting the dialog.

Clicking on the *Grid* tab brings forward the second page of the *Plot Map* dialog seen in Figure 6.4. Within this page, parameters can be set to specify the desired appearance of latitude/longitude lines and their labeling on the map. The first checkbox is for the option to display latitude/longitude lines on the map. If this option is selected the user can specify how far apart these lines should be drawn in the edit boxes next to *Latitude Grid Width* and *Longitude Grid Width*. If a grid is to be drawn, the next option available is whether or not to label the grid lines. When selected, all of the grid lines are labeled unless the user specifies limits on labeling in the designated edit boxes. In the case of a cylindrical map projection, the labels are placed outside of the edges of the map. For the

other map projections, labels are placed along the parallel of latitude closest to the center of the plot field unless the *Force Lon Labels to Equator* checkbox is selected. In that case, labels are placed along the equator regardless of where it lies in the plot. The last option on this page is the *Highlight Lat/Lon Zero-Pt Line* checkbox. If selected, the Equator and Prime Meridian are plotted thicker than the other coordinate lines in order to be easily identifiable.

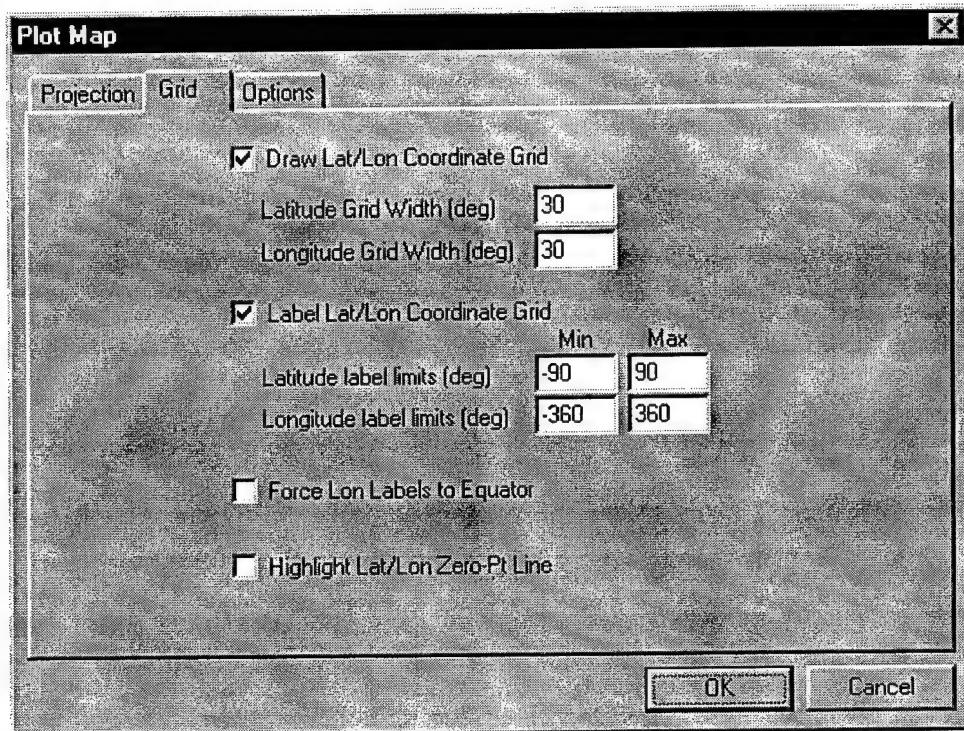


Figure 6.4. Plot Map dialog, Grid page

The *Options* page of the dialog, seen in Figure 6.5, is where the map appearance, source, and attributes are set. In the *Map Appearance* section of the dialog page, any combination of the three checkboxes can be selected. The first checkbox is for a *Transparent Map*, which is a map drawn with no color for land masses or bodies of water. The benefit of using a transparent map is that other graphics can be “seen through” the map when manipulated in the *Graphics Window* (see Section 2.7). The second option is for *Continental Outline*, which outlines the borders of land masses. The last checkbox in this section is *Outline Border for Map*, which draws a border around the entire map. The colors for the map features can be set in the *Map Attributes* section on the right side of the page. Clicking on any of the color buttons brings up a dialog from which a new color can be chosen. The colors chosen for background, land, and lakes are only relevant if the user does not select a *Transparent Map* to be drawn. Similarly, the colors for geographic lines, continental lines, and map border are relevant if the user chooses to plot those features. The line thickness for geographic lines, continental lines, and map border can be set in a range from *Normal* to *Jumbo* using the drop-down boxes next to the color buttons. Finally, the *Map Source* section is where the user selects

whether the map should be *High Resolution*, *Low Resolution*, or from a *User-Supplied Map File*. Both the *High Resolution* and the *Low Resolution* sources will draw from a self-contained database, but the difference between the two is that the *Low Resolution* map omits some details such as small islands and lakes. A *User-Supplied Map File* with the correct format as described in Section 8.5 can be used as the source of the plot data. If this option is selected, the user is prompted to select the source file upon exiting the *Plot Map* dialog with *OK*. The *Reset* button located at the bottom of the dialog is used for restoring all selections to default values.

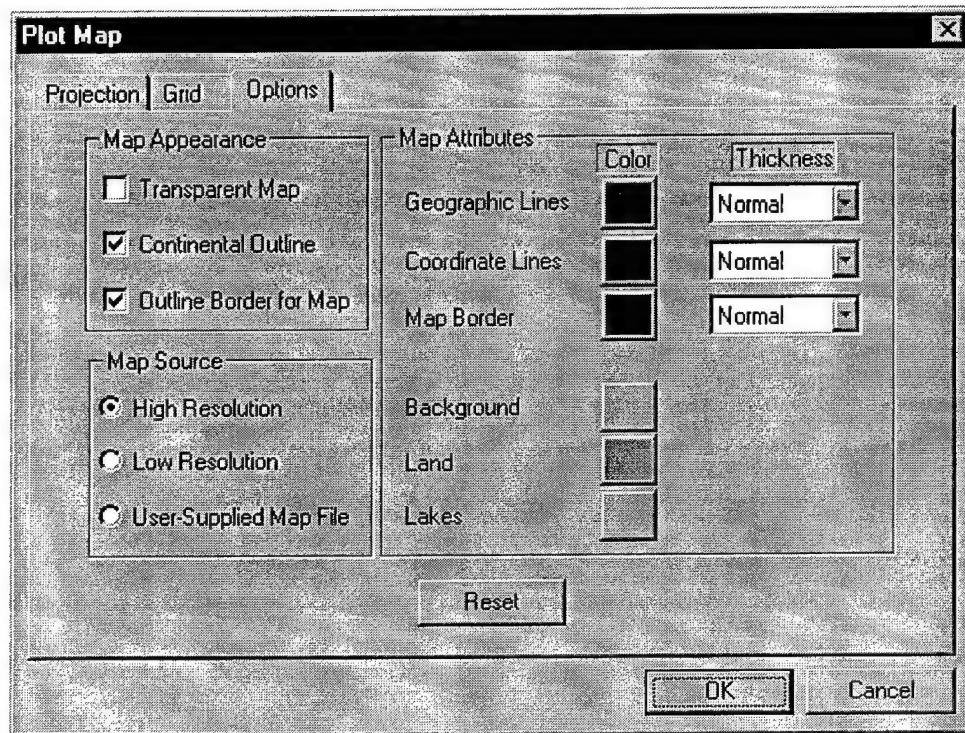


Figure 6.5. Plot Map dialog, Options page

6.2 Satellite Position

This command is used to plot a satellite icon at the geographic and/or space position for a user-selected time based on whichever of the ephemeris files is active and depending on the map projection in use. The *Plot Satellite Position* dialog, launched by either selecting *Satellite Position...* from the *Plot* menu or by clicking on the associated toolbar button, is shown in Figure 6.6. A list of active ephemeris files appears in the left side of the dialog. Selecting one of these files determines which satellite position to plot. The time span of the selected file is displayed below the file list in order to aid the user in specifying an appropriate time point in the edit boxes located to the right of the file list. The current map projection is identified below the time span, as it helps to explain the relevance of the *Plot Orbiting Satellite* and *Plot Sub-Satellite Position* checkboxes. The first option is only viable for three-dimensional map plots, namely Orthographic and Vertical Perspective, on which space position can be plotted. The second option for plotting ground position is available for all map types. Clicking on the *OK* button results in the

appropriate icon(s) being plotted on the map. Exiting the dialog with *Cancel* neither plots anything on the map nor saves any data entered into the dialog.

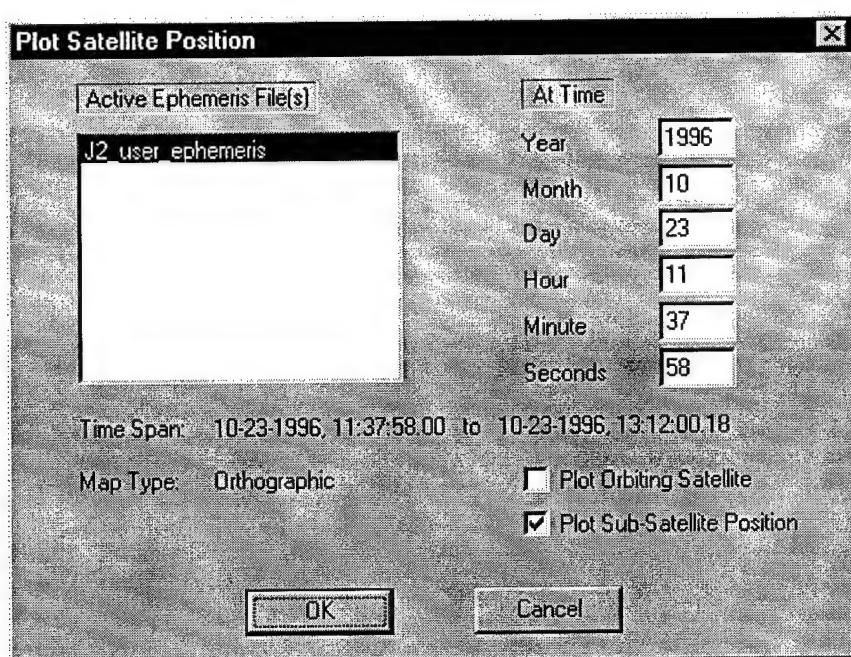


Figure 6.6. Plot Satellite Position dialog

6.3 Satellite FOV

Selecting *Satellite FOV...* from the *Plot* menu or clicking on the corresponding toolbar button brings up the dialog in Figure 6.7 for setting up the plot of a field-of-view seen by a satellite antenna. A list of active ephemeris files appears in the left side of the dialog. The satellite FOV is plotted from whichever file the user selects. The time at which the FOV is to be plotted can be specified in the edit boxes to the right of the file list. The time span of the selected ephemeris file is displayed below the file list in order to aid the user in specifying an appropriate time within the bounds of the file. Antenna and attitude parameters can be set by clicking on the respective buttons located at the bottom of the dialog. Descriptions of the procedures for setting these parameters can be found in Sections 5.1 and 5.2. Note that the *Set Attitude Parameters* button is activated when the *Use Attitude Data* button is selected. After exiting the dialog by clicking on *OK*, the satellite FOV is plotted on the map. If the *Cancel* button is pressed, none of the data entered into the dialog is saved.

6.4 Satellite Tracks

This function is used to plot the line path traced by an earth-orbiting satellite. The dialog launched by selecting *Satellite Tracks...* from the *Plot* menu or by clicking the associated

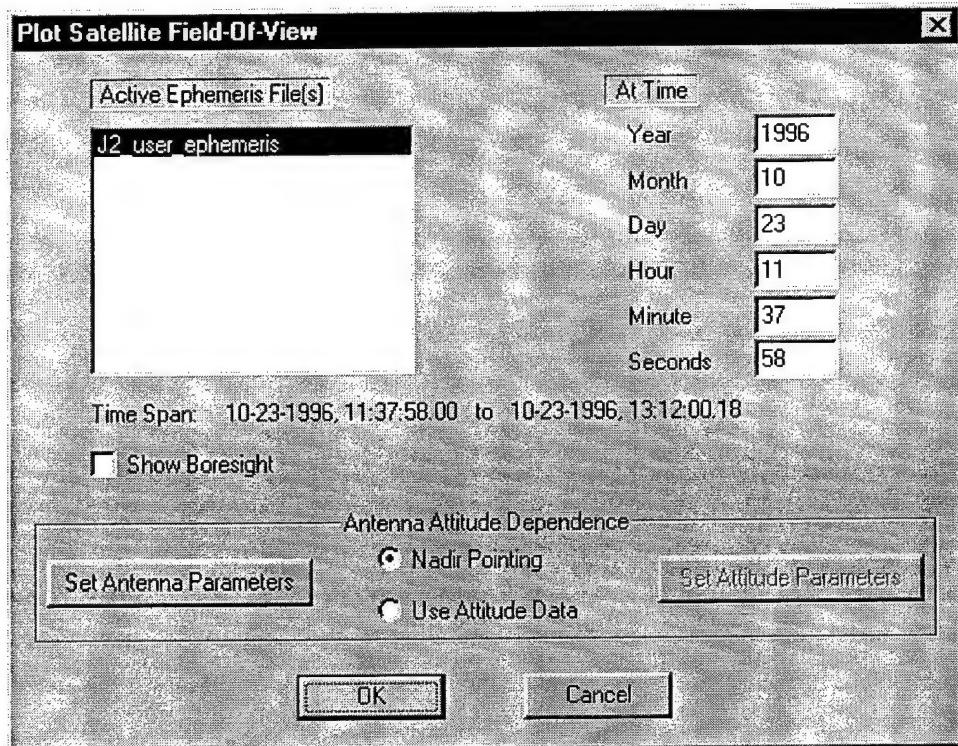


Figure 6.7. Plot Satellite Field-Of-View dialog

toolbar button is shown in Figures 6.8 and 6.9. This dialog has two tabbed pages for data entry: *Parameters* and *Time Tags*.

In the *Parameters* page of the *Plot Satellite Tracks* dialog, a list of active ephemeris files is located on the left side. By selecting a file, the user determines which satellite track to plot. The *Start Time* and *Stop Time* of the selected file are displayed in the respective places to the right of the file list. The *Step Size* is the time interval in seconds between successively plotted points along the track. Since the plotted track consists of a series of connected straight line segments, the smoothness of the plot is a function of step size. A smaller step size implies a smoother plot but also a longer execution time. The *Stop Time* can be set according to a user-supplied number of *Revolutions*. It may be easier to specify, say, three orbits around the earth instead of manually assigning a *Stop Time*. The new *Stop Time* is displayed when the user clicks on the *Show Conversion* button. This step is not necessary, as OATS will compute the *Stop Time* upon exiting the dialog anyway; rather it is there for the convenience of the user. Similar to the *Plot Satellite Position* dialog, the current map projection is identified to explain the choices of *Plot Orbiting Satellite* and *Plot Sub-Satellite Position*. The space track option is available for three-dimensional maps only, and the ground track is a viable option for any of the map projections.

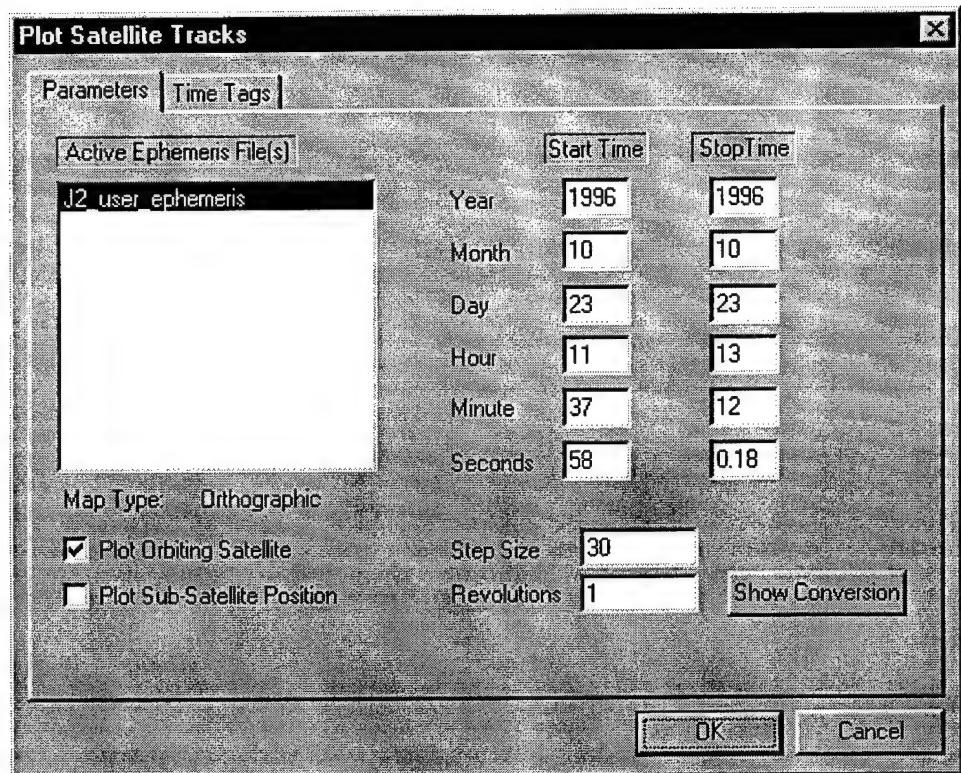


Figure 6.8. Plot Satellite Tracks dialog, Parameters page

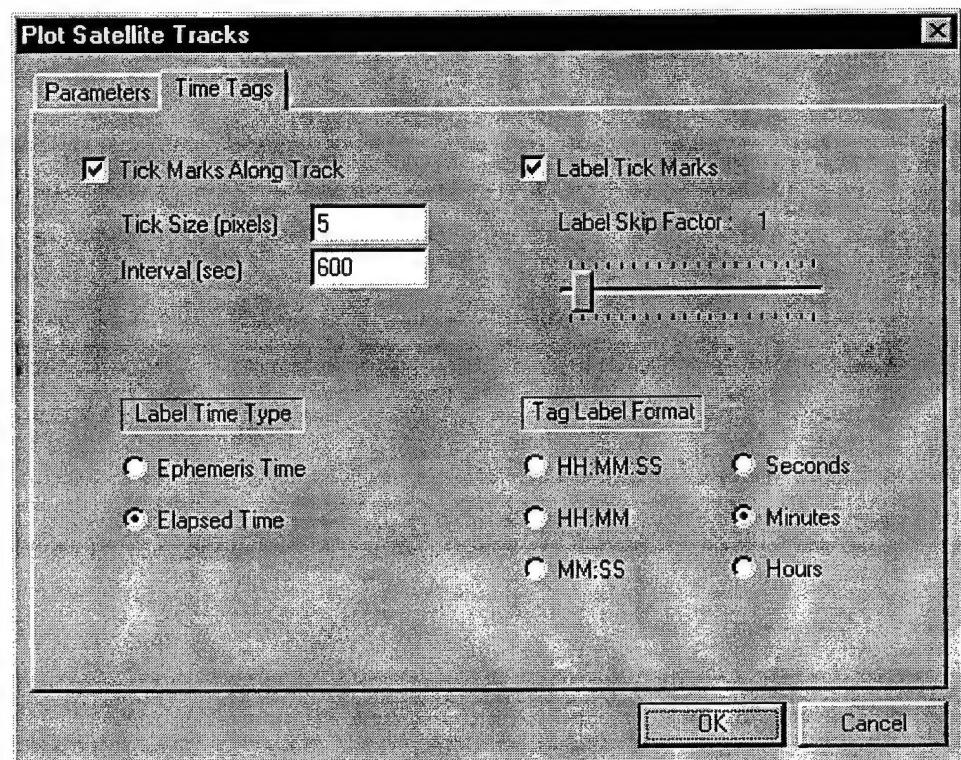


Figure 6.9. Plot Satellite Tracks dialog, Time Tags page

In the *Time Tags* page of the *Plot Satellite Tracks* dialog, the user can select whether or not to display tick marks along the satellite tracks, how frequent the tick marks should be placed, and how the tick marks should be labeled. The first checkbox in the upper left corner of the page is for selecting the display of tick marks. If user chooses not to check this box, the rest of the settings on the page are irrelevant. The size of the tick marks can be set here as well as the time interval in seconds between tick marks. It is advisable to choose an interval for time tags that is a multiple of the *Step Size* used to plot the track. In the upper right corner of the page is a checkbox to determine whether or not the tick marks should be labeled. If so, the frequency of the labeling can be set using a slide bar. The type of labeling can be selected in the bottom right of the page to coincide with the *Elapsed Time* from the start time of the plot or the *Ephemeris Time* derived from the designated file. Finally, the format of the label can be one of six choices given in the bottom left of the dialog page. Integral values of *Seconds*, *Minutes*, or *Hours*, may be chosen or a formatted combination of hours (*HH*), minutes (*MM*), and seconds (*SS*). When the dialog is exited by clicking on *OK*, the satellite tracks are plotted on the map. If the *Cancel* button is pressed, none of the data entered into the dialog is saved.

6.5 Satellite Swath

Selecting *Satellite Swath...* from the *Plot* menu or clicking on the corresponding toolbar button brings up the dialog shown in Figure 6.10 for setting up the plot of a swath swept out by the satellite FOV over a time interval by an earth-orbiting satellite. Swath coverage is computed with one of two possible algorithms. One algorithm sums the area covered by consecutive fields-of-view spaced at equal stepped intervals, and it handles any attitude configuration of the satellite. The other algorithm computes initial and final fields-of-view and then incremental coverage boxes as wide as the FOV and transverse to the satellite ground track. This algorithm is limited to nadir pointing antennas.

A list of active ephemeris files is located on the left side of the *Plot Satellite Swath* dialog. By selecting a file, the user determines which satellite swath to plot. The *Start Time* and *Stop Time* of the selected file are displayed in the respective places to the right of the file list. The user can alter these times as long as they lie within the time period covered by the ephemeris file. The *Step Size* is the time interval in seconds between successively plotted FOVs along the track. A smaller step size implies a smoother plot but also a longer execution time. The *Stop Time* can be set according to a user-supplied number of *Revolutions*. A new *Stop Time* is displayed when the user enters a number of revolutions and clicks on the *Show Conversion* button. This step is not necessary, as OATS will compute the *Stop Time* upon exiting the dialog anyway; rather it is there for the convenience of the user. Antenna and attitude parameters can be set by clicking on the respective buttons located at the bottom of the dialog. Descriptions of the procedures for setting these parameters can be found in Sections 5.1 and 5.2. Note that the *Set Attitude Parameters* button is activated when the *Use Attitude Data* button is selected. After exiting the dialog by clicking on *OK*, the satellite swath is plotted on the map. If the *Cancel* button is pressed, nothing is plotted on the map and none of the data entered into the dialog is saved.

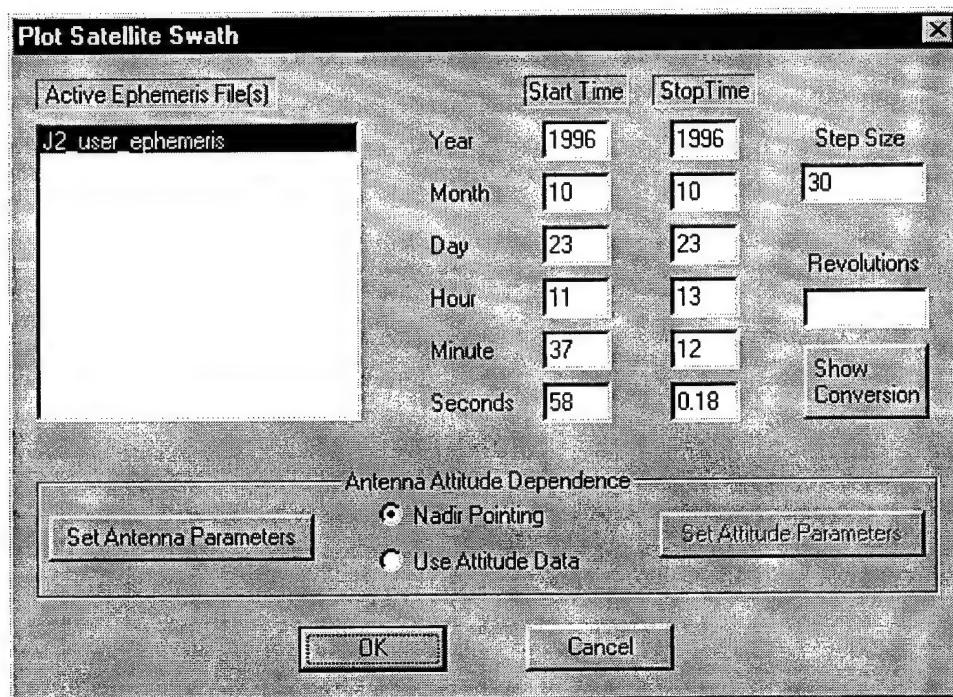


Figure 6.10. Plot Satellite Swath dialog

6.6 Target Position

Figure 6.11 displays the dialog launched by selecting *Target Position...* from the *Plot* menu or by clicking on the corresponding toolbar button. This dialog is designed to allow the user to add, select, and display target data. As many as 100 targets can be plotted on a map at user-defined geographic positions.

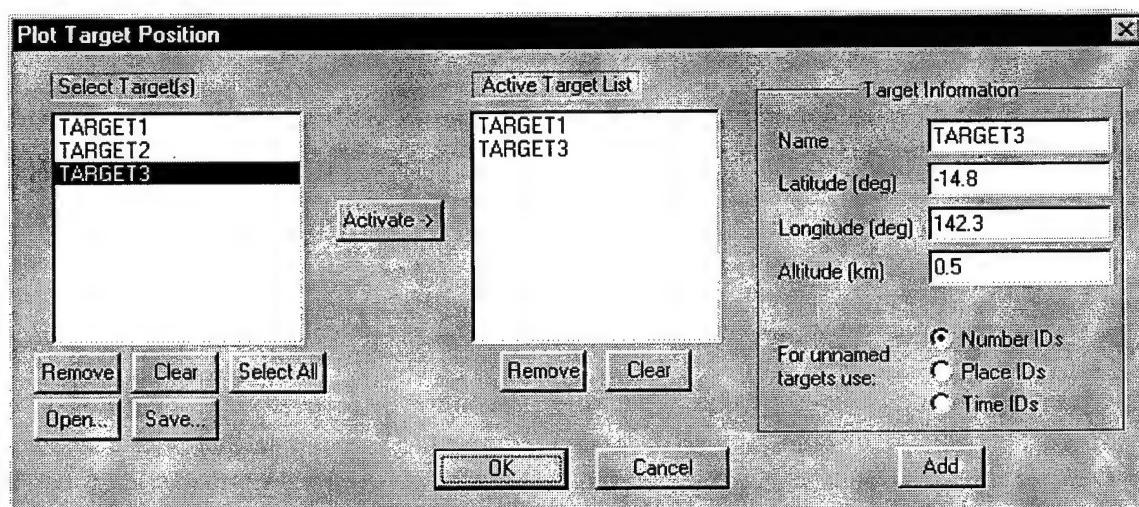


Figure 6.11. Plot Target Position dialog

The window on the left side of the dialog contains a list of all defined targets. Multiple targets can be selected in this list and then sent to the active target list by clicking on the *Activate* button. Only those targets in the active list are plotted. Targets can be deleted from either list by selecting them and clicking the associated *Remove* button. A list can be emptied if the *Clear* button beneath the list is pressed. Clicking the *Select All* button highlights all targets in the first list for the purpose of either activation or removal. The target list can be derived from a text file in the format described in Section 8.3 by clicking the *Open...* button and selecting the file from the appropriate directory in the dialog that appears. A target list may also be saved to a file by clicking on *Save...* and designating a file name in the resulting dialog. The area on the right side of the dialog titled *Target Information* is used either to display information about a target selected in one of the lists or to enter information about a new target to be added to the lists. To add a new target, the text fields for *Latitude*, *Longitude*, and *Altitude* must be filled in. The target *Name* can consist of any alphanumeric characters. Target names may even be repeated as long as the qualifying latitude, longitude, and altitude are not all identical. The new target is inserted into the lists after the user clicks the *Add* button in the bottom right corner of the dialog. If the *Name* field is left blank when *Add* is pressed, a name will automatically be generated for the target according to the selected choice of *Number IDs*, *Place IDs*, or *Time IDs*. Examples of these names are as follows:

Type	Example	Description
Number ID	TARG_0001	Target numbers 1 through 9999
Place ID	TARG_+1241_12386	Target at latitude +12.41°, longitude 123.86°
Time ID	TARG_12/23/94_09:25:18	Target created at 9:25:18 AM on December 23, 1994

Exiting the dialog by clicking on *OK* causes the targets in the active list to be plotted on the map. If *Cancel* is pressed, none of the data entered into this dialog is saved.

6.7 Ground Station Position

Similar to plotting target position, this function is used to plot a set of ground stations at user-defined geographic positions. The dialog launched by selecting *GS Position...* from the *Plot* menu or by clicking on the corresponding toolbar button is shown in Figure 6.12. This dialog functions in almost exactly the same fashion as the *Plot Target Position* dialog with very few differences. Up to 31 ground stations can be placed in the active list for plotting. There is an additional text field for *Elevation Mask* that does not exist in the previously discussed dialog. There is also no automatic name generation for ground stations with the *Name* field left blank. The user has the option to have the ground stations' names plotted alongside the icon on the map by clicking in the checkbox in the bottom right of the dialog. The ground stations are plotted on the map when the user clicks *OK* to exit this dialog. None of the information entered into the dialog is preserved if the *Cancel* button is pressed.

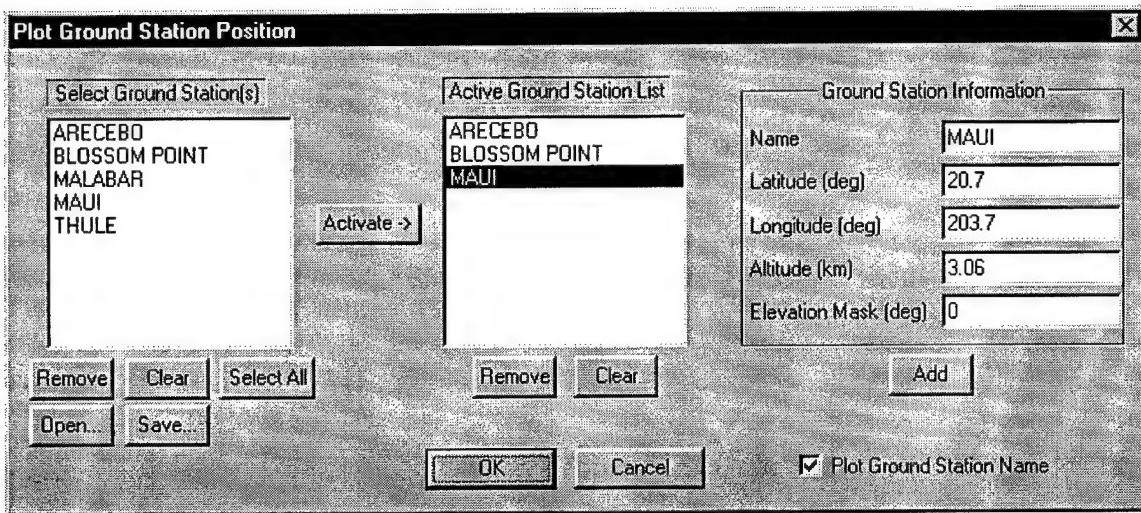


Figure 6.12. Plot Ground Station Position dialog

6.8 Ground Station FOV

Selecting *GS FOV...* from the *Plot* menu or clicking on the corresponding toolbar button brings up the dialog shown in Figure 6.13 for setting up the plot of fields-of-view for every ground station in the active list. At this time, OATS only provides for a circular ground station field-of-view.

A ground station FOV must be linked to the altitude of a satellite that it is trying to see. The user can choose the *Fixed Value of Satellite Altitude* option in the dialog and specify the satellite altitude in kilometers in the text box below. The other option is *Altitude Determined from Time of Satellite Position*, which means the altitude is derived from the time and location of a previously plotted satellite position or FOV. If the latter option is used and there is no currently plotted satellite position or FOV, no ground station FOV is plotted on the map. Clicking on *OK* to exit the dialog causes the FOVs to be plotted on the map. If the *Cancel* button is pressed, none of the data entered in the dialog is saved.

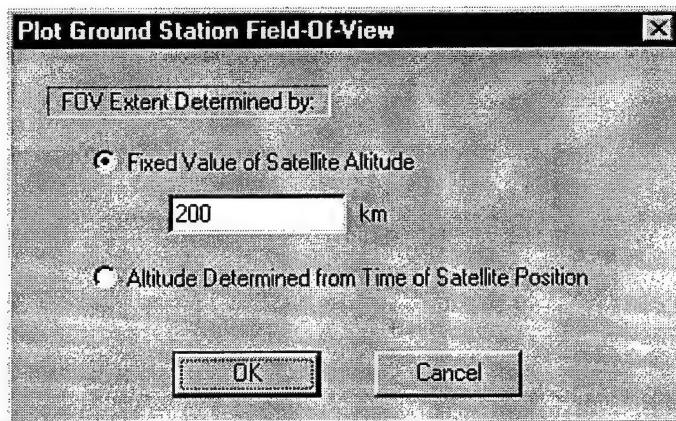


Figure 6.13. Plot Ground Station Field-Of-View dialog

6.9 Density Contours

Density contours are solid area shadings using color over a worldwide mesh to show satellite coverage by the color value in each mesh element. These area contours are based on a user-defined set of ephemeris files, antenna settings, and ground stations. The dialog launched by selecting *Density Contours...* from the *Plot* menu or by clicking on the corresponding toolbar button is displayed in Figure 6.14.

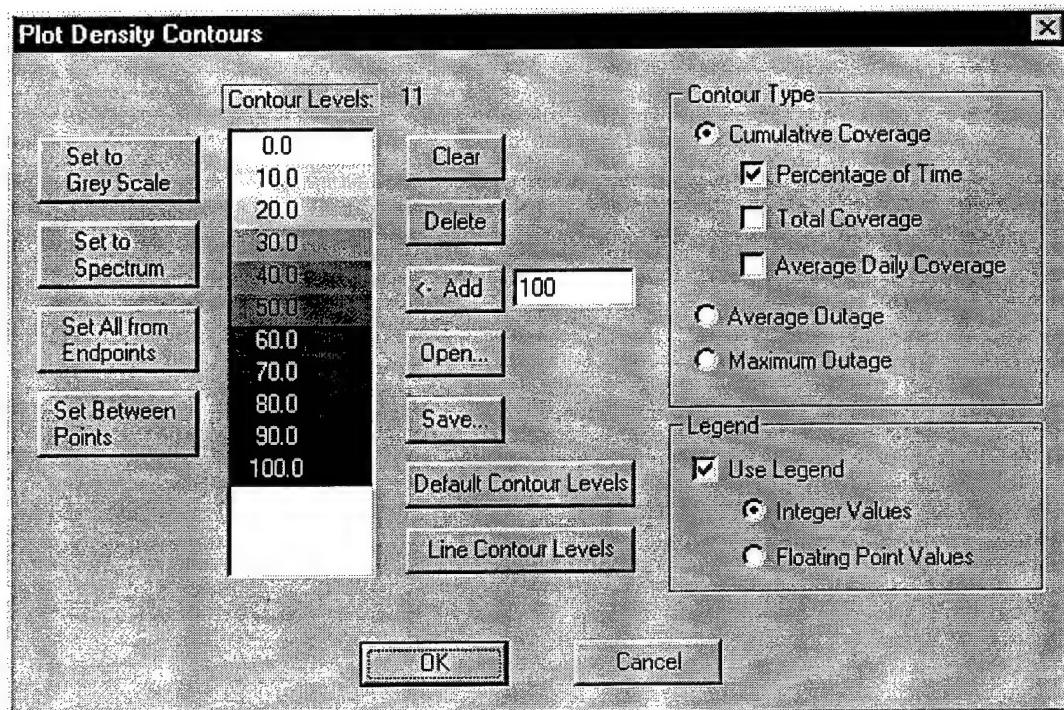


Figure 6.14. *Plot Density Contours* dialog

Central to this dialog is a list of the contour values and a swatch of their associated color. Contouring is performed such that each level listed represents a range of coverage values with the value shown equaling the lowest end of the range for a given color. The buttons located to the right of the levels list are used to modify the contour values whereas the buttons to the left of the list are used to modify the colors associated with the values. Clicking the *Clear* button causes the deletion of all entries in the list. Multiple levels in the list can be deleted by selecting them and then hitting the *Delete* button. Levels can be added to the list by entering a value in the text box and clicking *Add*. Note that duplicate levels are not allowed. Levels values can be retrieved from a text file by clicking on the *Open...* button and selecting the file from the resulting dialog. The file must be in the format as described in Section 8.6. Similarly, the levels and associated colors in the list can be saved to a file by clicking on the *Save...* button and designating the name of text file to which the information is written. Clicking on *Default Contour Levels* imports a standard list of levels for the current selection in the *Contour Type* section of the dialog. If values have previously been set in the *Plot Line Contours* dialog, clicking on the *Line Contour Levels* button can retrieve those values for use in this dialog. The default color

settings are the colors from the spectrum (i.e. red through violet). However, if the *Set to Gray Scale* button is pressed all the color swatches in the list will be converted to grayscale values ranging from white to black. The *Set to Spectrum* option converts all the swatches to color values ranging from red to violet. Any individual swatch may be set to a different color by double clicking on the level in the list. A color-picker dialog appears from which the user can select from the given choices of colors or derive a custom color. Clicking on *Set All from Endpoints* will convert the color swatches to range from the first color in the list to the last. A range of swatches can be set from any two points in the list by clicking on one level then clicking on another level while holding down the Control key, then pressing the *Set Between Points* button.

The type of contour to be plotted can be selected from the five possible choices in the upper right corner of the dialog. The *Average Outage* and *Maximum Outage* are given in terms of minutes per day that a mesh region is not covered (i.e. outage means mesh region is “out of view”). The *Cumulative Coverage* (time mesh region is in view) can be expressed as a *Percentage of Time*, *Average Daily Coverage* in minutes, or *Total Coverage* in minutes.

The user has the option to display a legend on the screen that describes the density contours by level values and color swatches. The levels are shown either with integer (truncated) values or floating point values depending on the choice made with the buttons in the lower right corner of the dialog. When the legend is plotted, it is automatically placed in the upper left corner of the document window of the OATS application. However, the legend can be moved to a location more suitable to the user. Clicking on the legend with the right mouse button brings up a menu with one choice: *Move*. Selecting this choice with the left mouse button allows the user to then move the mouse (with no buttons depressed) to the desired location and click the right mouse button to drop the legend in its new place. This process can be repeated as many times as necessary until the user is satisfied with the placement of the legend.

Upon exiting the dialog with *OK*, a new dialog appears from which the user must select the graphical coverage file from which the contours are to be drawn. The text file could have been previously generated from the *Graphical Coverage* dialog (see Section 5.4) or it could be an externally created file with the format as described in Section 8.7. After selecting a file and clicking on *OK*, the density contours and the legend, if so chosen, are plotted on the map. Exiting the dialog with *Cancel* will cause any data entered into the dialog to be erased.

6.10 Line Contours

Line contours are isochrones connecting elements of a worldwide mesh that show satellite coverage by value of each mesh element. These line contours are based on a user-defined set of ephemeris files, antenna settings, and ground stations. The dialog launched by selecting *Line Contours...* from the *Plot* menu or by clicking on the corresponding toolbar button is displayed in Figure 6.15.

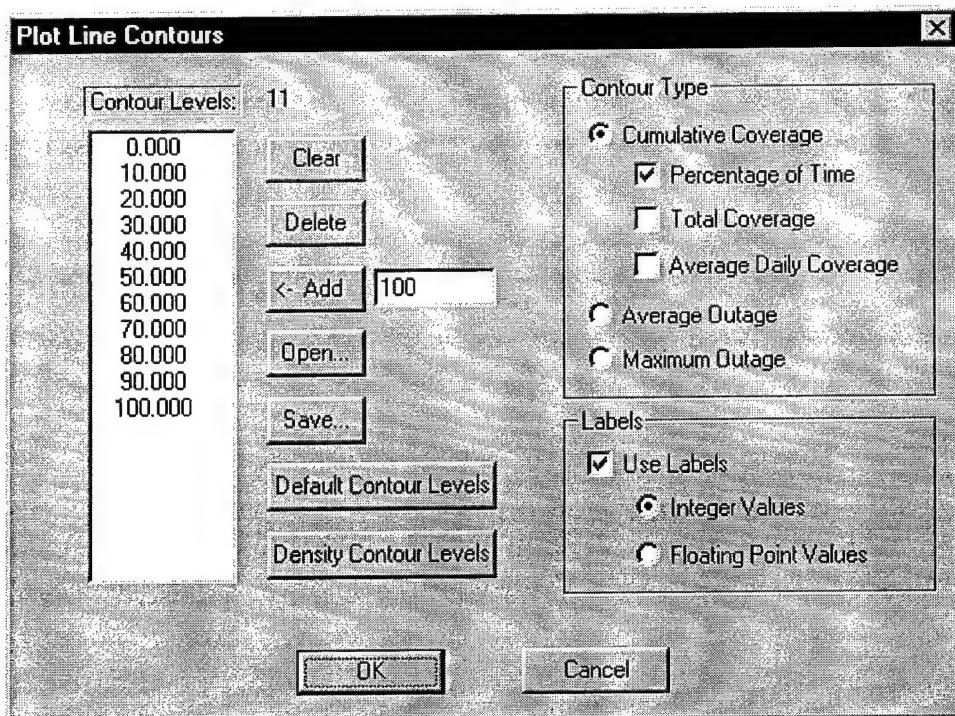


Figure 6.15. Plot Line Contours dialog

The *Plot Line Contours* dialog is used in exactly the same manner as the dialog for plotting density contours. The only differences are the absence of color swatches (and related buttons) and the use of labels versus a legend. The user may choose to label the contour lines by clicking the checkbox next to *Use Labels* and selecting whether the labels should appear as integer or floating point values. Clicking on the *OK* button brings up a dialog from which the user must select the graphical coverage file from which the contours are to be drawn. The text file could have been previously generated from the *Graphical Coverage* dialog (see Section 5.4) or it could be an externally created file with the format as described in Section 8.7. After selecting a file and clicking on *OK*, the line contours and the labels, if so chosen, are plotted on the map. Exiting the dialog with *Cancel* will cause any data entered into the dialog to be erased.

6.11 Coverage Snapshot

A coverage snapshot is defined as the instantaneous interaction of the fields-of-view of several spacecraft. This interaction can be quite complex depending on the number of spacecraft involved, their positions, their antenna definitions, their attitudes, and the type of interaction (unions versus intersections). Snapshots are somewhat analogous to doing coverage analysis using Venn diagrams. The dialog launched by selecting *Coverage Snapshot...* from the *Plot* menu or clicking on the corresponding toolbar button brings up the two-page dialog, shown in Figures 6.16 and 6.17, for setting up the snapshot plot.

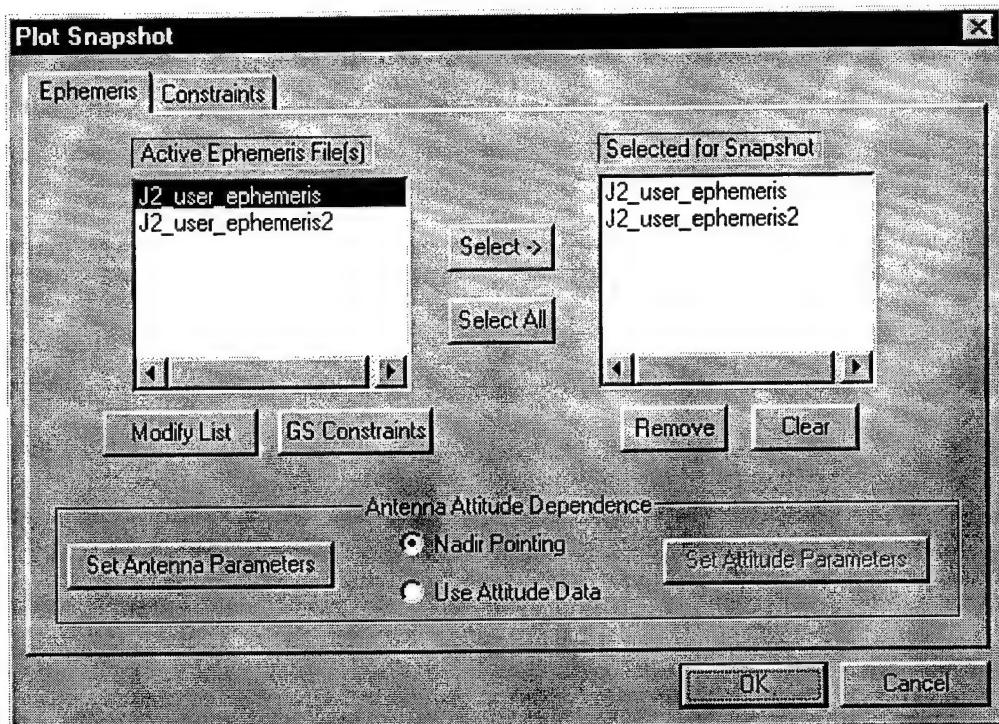


Figure 6.16. Plot Snapshot dialog, Ephemeris page

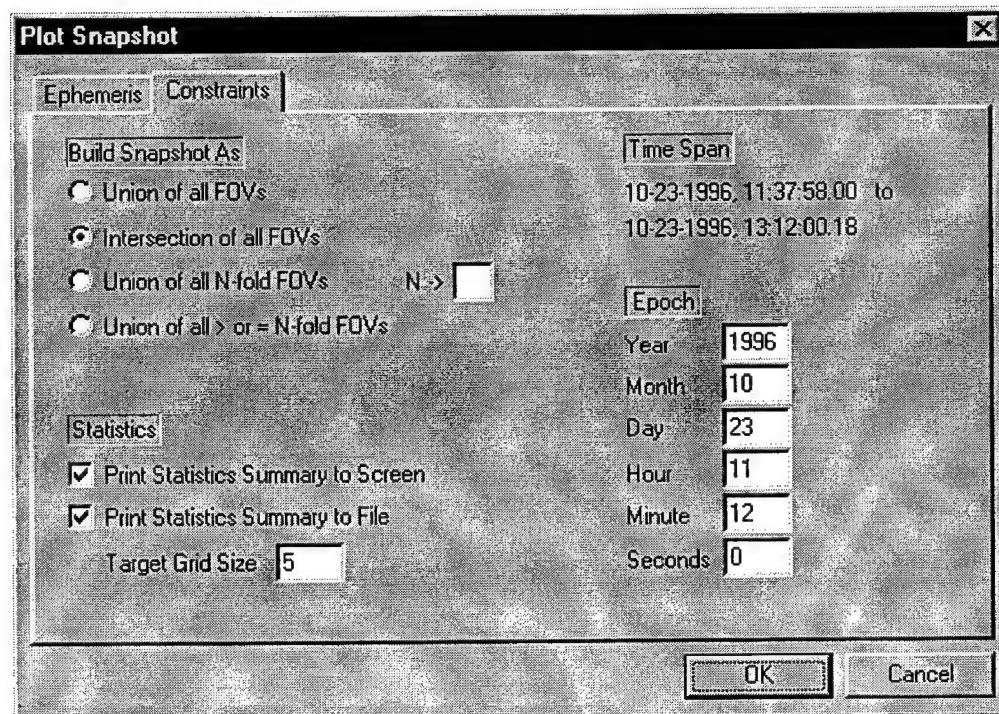


Figure 6.17. Plot Snapshot dialog, Constraints page

In the *Ephemeris* page of the dialog, multiple files in the active ephemeris file list can be selected for use in the coverage snapshot by selecting them and clicking on the *Select* button. The active list can be altered by clicking the *Modify List* button and following the procedure outlined in Section 4.1. Files that have been selected for the snapshot can be removed from that list by clicking on the file names and then clicking the *Remove* button. Pressing the *Clear* button causes the removal of all names from the *Selected for Snapshot* list. Similar to the methodology employed in the *Tabular Coverage* and *Graphical Coverage* dialogs (see Sections 5.3 and 5.4), the ground station constraints, and antenna and attitude parameters can be set for each ephemeris file.

The second page of the dialog is where the user can set constraints for the coverage snapshot. Union or intersection of FOVs can be selected as well as a union related to N-fold coverage regions, where N is specified by the user. For example, a snapshot could be formed from the coverage area defined by the union of the FOVs of any 2 out of 3 satellites. The time span covering all ephemeris files selected for the snapshot is displayed in order to aid the user in selecting a time for the snapshot in the *Epoch* section of the dialog page. The user may elect to display statistics of the snapshot on the screen and/or in a text file by selecting one or both choices in the bottom left corner of the page. The *Target Grid Size* determines the global grid used to compute the statistics, namely the area covered by the snapshot. Smaller grid sizes imply greater accuracy but longer execution time.

Clicking on the *OK* button initiates the coverage snapshot plot. If the *Print Statistics Summary to File* option was selected on the *Constraints* page, a dialog is displayed in which the user must specify the name of the text file to which to write the statistics. Otherwise the snapshot is plotted on the map. If the *Cancel* button is pressed, none of the data entered in the dialog is preserved.

6.12 Sun and Shadows

This plot command is used to plot the sun's geographic sub-solar position, the moon's geographic sub-lunar position, the terminator line, defined lines of twilight, and the area of the earth's surface in shadow. Figure 6.18 shows the dialog launched when *Sun and Shadows...* is selected from the *Plot* menu or the corresponding toolbar button is pressed. In the left side of the dialog there are checkboxes available so that the user can select which of the aforementioned features to plot. The right side of the dialog contains edit boxes in which the user enters the year, month, day, hour, minute, and seconds of the time at which the sun and shadows should be plotted. Clicking the *OK* button induces plotting of the selected features to take place on the map. Any information entered into the dialog is lost if exited using the *Cancel* button.

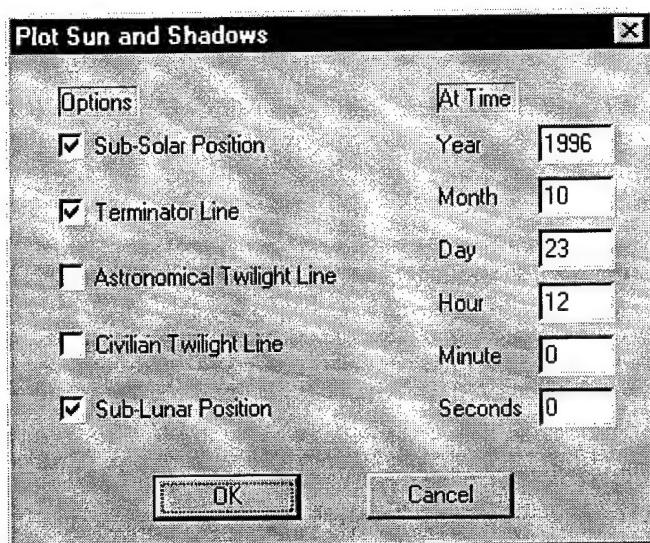


Figure 6.18. Plot Sun and Shadows dialog

6.13 Lines, Shading, and Icons

All of the features of objects that are plotted over a map can be set through the selections in the *Attributes* menu (or corresponding toolbar), seen in Figure 6.19.

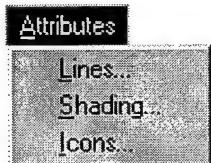


Figure 6.19. Attributes menu

The dialog launched by selecting *Lines...* from the *Attributes* menu is shown in Figure 6.20. Within this dialog, the color and thickness of lines used for various graphical displays can be set. Clicking on any of the *Color* buttons brings up a dialog from which a new color can be selected. The *Thickness* for each item can be chosen from a drop-down list of four choices ranging from *Normal* to *Jumbo*. The *Reset* button at the bottom of the dialog is used for restoring all selections to default values. Any changes made in the dialog are saved for future plotting when the user clicks the *OK* button but are not preserved if *Cancel* is pressed.

Figure 6.21 displays the dialog brought up by selecting *Shading...* from the *Attributes* menu. The color and pattern of shading used for certain plotted items are set within this dialog. Clicking on any of the *Color* buttons brings up a dialog from which a new color can be selected. The *Pattern* for each item can be chosen from a drop-down list of eight choices. The *Reset* button at the bottom of the dialog is used for restoring all selections to default values. Exiting the dialog by clicking *OK* preserves any changes for future plotting. However, all changes are lost by clicking on the *Cancel* button.

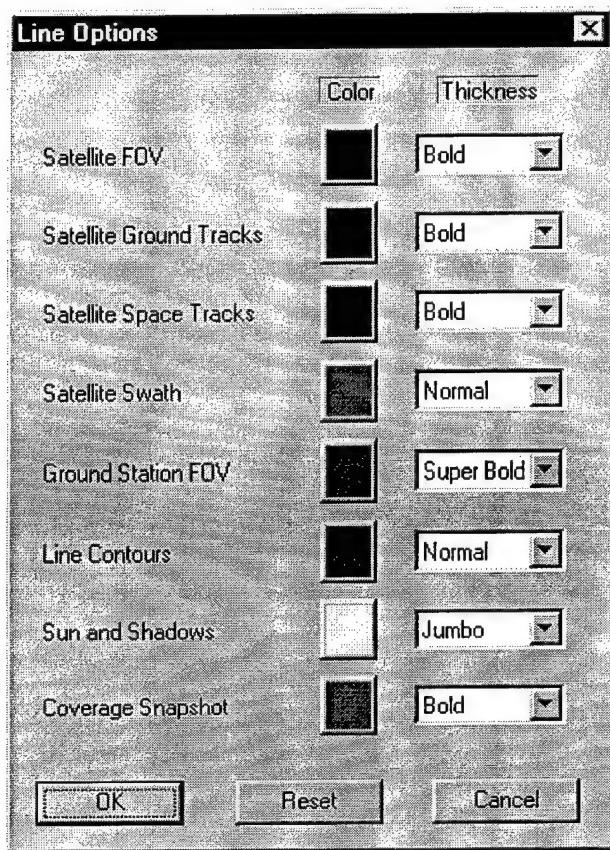


Figure 6.20. Line Options dialog

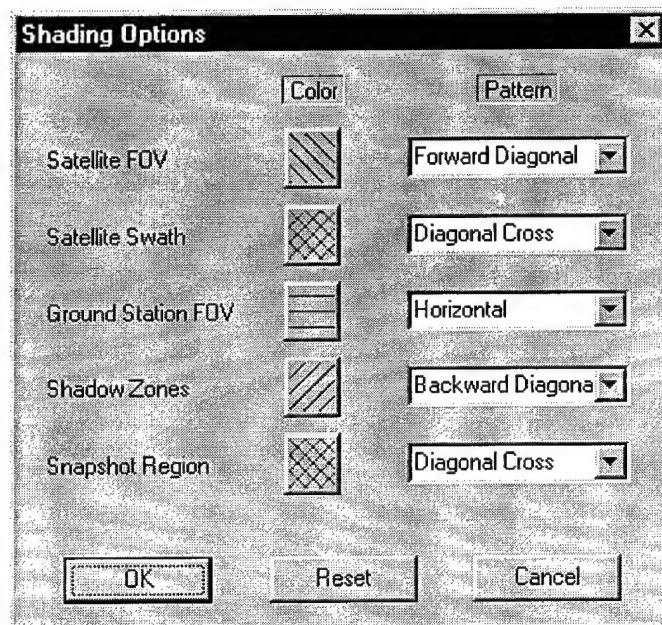


Figure 6.21. Shading Options dialog

Selecting *Icons...* from the *Attributes* menu brings up the dialog seen in Figure 6.22. The color and size of plotted icons are set here as well as the type of icon for plotting target position and the cursor used in *Locator Mode* (see Section 6.14). Clicking on any of the *Color* buttons brings up a dialog from which a new color can be selected. The *Size* for each item can be chosen from a drop-down list of four choices ranging from *Small* to *X-Large*. The *Reset* button at the bottom of the dialog is used for restoring all selections to default values. The *Style* of the target position icon and the locator cursor can be chosen from their respective drop-down lists, and any new icon selection is displayed on the left side of the dialog. Any changes made in the dialog are saved for future use when the user clicks the *OK* button but are not preserved if the dialog is exited with *Cancel*.

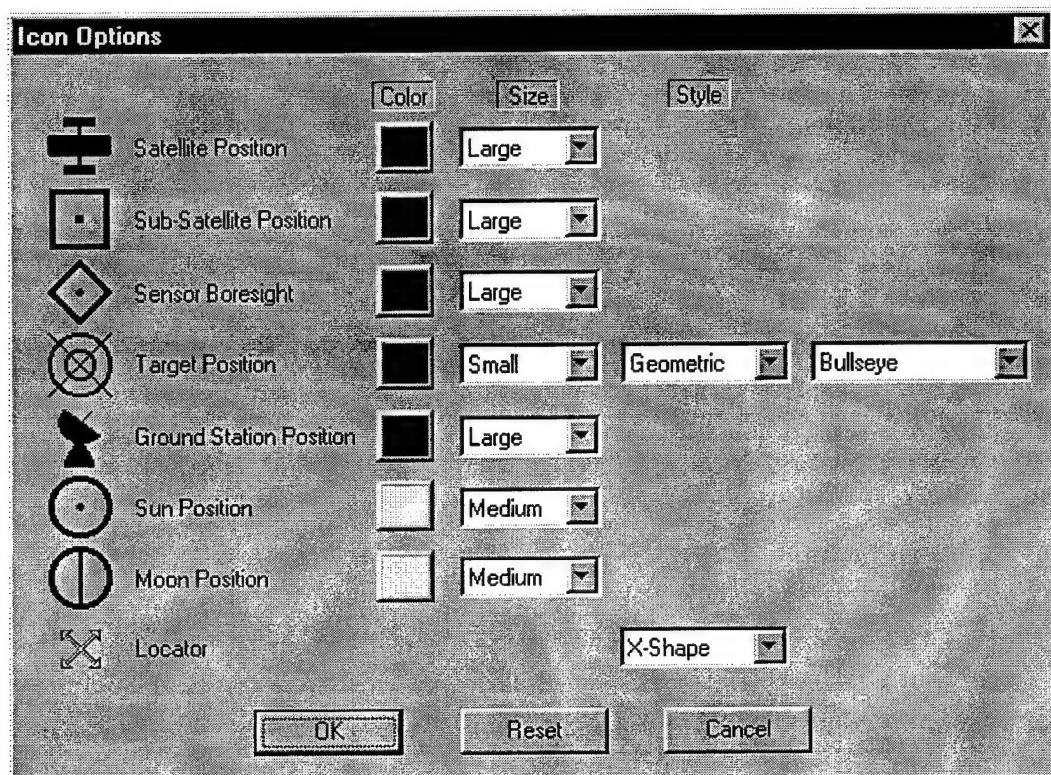


Figure 6.22. *Icon Options* dialog

6.14 Zoom and Locator Mode

From the *View* menu or the *View* toolbar, the user may select to zoom in or out of the graphics view. Zooming does not change the resolution of plotted data, but it does allow the image to be seen easier by making it larger or more compact. There are limits in place on how far in or out the user may zoom, and a grayed menu option or toolbar button designates when the limit has been reached.

When *Locator Mode* is turned on either through the *View* menu option or toolbar, the user can drag the mouse cursor over a plotted map and see the latitude and longitude of the point underneath the cursor displayed in the small window in the *View* toolbar. During

this mode, the mouse cursor has the appearance of whichever cursor is selected in the *Icons Options* dialog (see Section 6.13). When *Locator Mode* is turned off, the mouse cursor returns to its normal state. If there is no map currently plotted or the mouse cursor does not lie over the map, the display for the latitude/longitude is blank.

6.15 Editing Graphics

In the *Standard* toolbar (see Section 2.3) there are four buttons representative of functions used for editing the plotted objects on the screen. The first button is *Select Graphics* which, when pressed, will place a dotted-line box around all of the graphics in the document window. The ability to select the graphics is useful if the user wishes to copy them and paste them in another application. The box is resizable and moveable and can be removed from the screen by clicking the right mouse button anywhere within the document window. After the selection box is in place, click on the *Copy* button (or type *Ctrl+C* as a shortcut) to place the picture on the Windows clipboard making it available to applications that can import graphics. An alternate method for creating the selection box is to click the left mouse button in the document window at one corner, drag the mouse to the corner diagonal from the first, and release the mouse button.

The user can add text to the document window, such as a title or other notes. Clicking on the *Add Text* button or selecting the option from the *Edit* menu and then clicking on a point in the document window brings up the dialog seen in Figure 6.23 in which to enter the desired text. Exiting this dialog by clicking the *OK* button causes the text to be placed on the screen at the chosen point. The text is not displayed if the *Cancel* button is pressed.

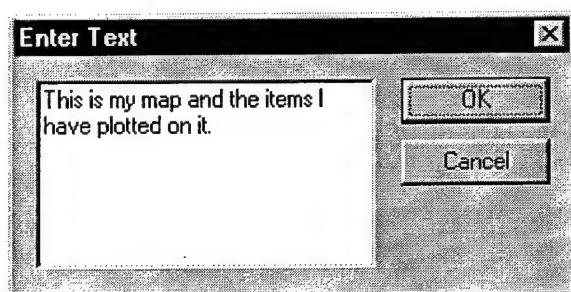


Figure 6.23. Add Text dialog

OATS also has the ability to “unplot” any of the graphics on the screen. Each time the *Undo* button (or menu selection) is pressed, the last object plotted on the screen is removed. The same result can be achieved via the *Graphics Window* as described in Section 2.7.

Chapter 7

Saving Your Work

Any of the data entered or graphics plotted during an execution of the OATS application is lost once the application is closed. However, the ability exists to save your work for future use in one of three ways: as a *Map*, a *Scenario*, or an *Environment*.

Selecting the *Save As...* option from the *File* menu brings up a dialog in which to specify the name of the file to be saved. This file will be designated an OATS file with the suffix .oat on the end of the filename. After closing this dialog by clicking *OK*, the dialog shown in Figure 7.1 appears. In this dialog the user chooses how much information from this execution of OATS is to be saved by designating which type of saved file it will be.

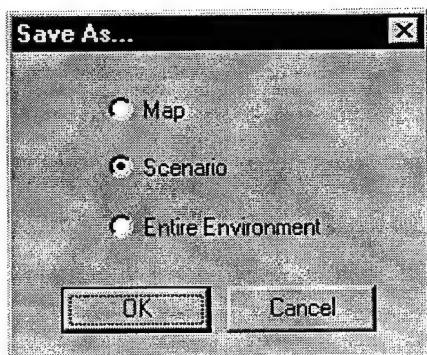


Figure 7.1. Save As dialog

A *Map* file contains only the information about the map including the parameters that were specified to create the map and the graphics for the map itself. No other plotted objects are saved in this format, nor is any other information saved that may have been entered into dialogs other than that for plotting the map. A *Scenario* file contains no information about any plotted graphics, but it does contain all the information about ephemeris files, attitude files, ground stations, targets, antenna parameters, attitude parameters, and all other constraints used for coverage runs. If the user chooses *Entire Environment* all graphics, attributes, and all data entered into every possible dialog are saved to the specified file.

When the OATS application is run again, the user can open up a file of any of the three types by selecting *Open...* from the *File* menu (or by clicking on the corresponding toolbar button) and selecting the desired *.oat file from within the launched dialog. Note that a *Scenario* file and a *Map* file can be opened up one after the other since they do not contain overlapping information.

Your work in the form of a hard copy of all plotted graphics may also be obtained by printing out the document. A preview of the printed document can be viewed by selecting *Print Preview* from the *File* menu or by clicking on the appropriate toolbar

button. Clicking on the *Print* button from the *Standard* toolbar or selecting *Print...* from the *File* menu executes the printing job. The quality of the printed-out version of the graphics may or may not be the same as the quality of the displayed graphics on the screen depending on the quality of the printer and the ability to print color graphics.

Chapter 8

File Formats

8.1 Orbital Elements

Four different orbit propagation models are used in OATS: PPT2 (Brouwer-Lyddane), RUK12 (4th order Runge-Kutta numerical integration), J2 (first order J₂ analytic), and SGP4 (USSPACECOM formulation of Brouwer solution with drag modeling). Each of the four models requires a different input vector file format with a total of six possible types of input formats for OATS. The RUK12 and J2 input file formats are non-specific and can be defined by any program utilizing such orbital element sets. However, the PPT2 and SGP4 have very specific native formats that are used to store and transmit element sets. The PPT2 orbit model uses NAVSPASUR One-Line Element Sets (OLES) which come in three varieties: PME, Charlie, and Z formats. The SGP4 model uses Two-Line Element Sets (TLES). Any of these six types of orbital element input files may be created by the user as a text file with any text editing program, imported from an external source, or created by OATS using the *Save* buttons in the orbital element data entry dialogs (see Chapter 3).

8.1.1 Charlie OLES

The Charlie format is valid at 0 hours Zulu. The OLES in Charlie format is 65 characters in length with the specific native format and the parameters making up the NAVSPASUR Charlie format one-line element set as follows:

IIII . AAAAAAA . MMMMMMM . DDDDD . EEEEEEE . WWWWWWW . NNNNNNN . IIIIIIIYYMMDD

Field	Description
IIII	satellite SDC number
AAAAAAA	mean anomaly, fraction of a revolution
MMMMMM	mean motion, radians/herg
DDDDD	decay, radians/herg/herg
EEEEEEE	Eccentricity
WWWWWWW	argument of perigee, fraction of a revolution
NNNNNNN	longitude of ascending node, fraction of a revolution
IIIIIII	angle of inclination, fraction of a revolution
YYMMDD	year / month / day

8.1.2 Z OLES

The Z format is also valid at 0 hours Zulu. The OLES in Z format is 69 characters in length with the specific native format and the parameters making up the NAVSPASUR Z format one-line element set as follows:

IIIIIRRRRAAAAAAAAMMMMMMDDDDEEEEEEEWWWWWWNNNNNNNNIIIIIIYYMMDD

Field	Description
IIII	satellite SDC number
RRRRR	revolution number
AAAAAAA	mean anomaly, fraction of a revolution
MMMMMM	mean motion, radians/herg
DDDDD	decay, radians/herg/herg
EEEEEEE	Eccentricity
WWWWWWW	argument of perigee, fraction of a revolution
NNNNNNN	longitude of ascending node, fraction of a revolution
IIIIIII	angle of inclination, fraction of a revolution
YYMMDD	year / month / day

8.1.3 PME OLES

The epoch of the PME format one-line element set is more generalized than the other two OLES formats, because space is allocated to specify the epoch to the nearest ten minutes. However, only the last digit of the year can be specified. The decade during which the OLES is valid is ambiguous in the context of the element set but can be specified in the orbital element entry dialog (see Chapter 3). The OLES in PME format is 69 characters in length with the specific native format and the parameters making up the NAVSPASUR PME format one-line element set as follows:

IIVRRRRRAAAAAAAAMMMMMMDDDDEEEEEEEWWWWWWNNNNNNNNIIIIIIYYMMDDHHM

Field	Description
II	satellite SDC number
V	version number
RRRRR	revolution number
AAAAAAA	mean anomaly, fraction of a revolution
MMMMMM	mean motion, radians/herg
DDDDD	decay, radians/herg/herg
EEEEEEE	eccentricity
WWWWWWW	argument of perigee, fraction of a revolution
NNNNNNN	longitude of ascending node, fraction of a revolution
IIIIIII	angle of inclination, fraction of a revolution
YMMDDHHM	year / month / day / hours / tens of minutes

8.1.4 TLES

The two-line element set contains two lines, each of which is 69 characters in length. If a data field is not specifically called out in the explanation below, then the TLES must match that field exactly as shown. Some of the data fields, e.g. international designator, are typically shorter than the maximal field size shown. Note that the satellite number is shown as an integer. The overwhelming majority of uses of this field do show it as a number. However, in some rare cases non-numeric fields have been seen in the

literature. OATS is capable of treating this as an alphanumeric field, even though it is probably safest for users to continue to think of it and treat it as a number. The specific native format and parameters making up the USSPACECOM TLES format two-line element sets used in OATS are as follows:

```
1 nnnnnnU YYLLL A YYDDD.DDDDDDDD 0.XXXXXXXXXX ZZZZZ-J GGGGG-K T SSSS
2 nnnnn III.IIII NNN.NNNN EEEEEEE WWW.WWWW AAA.AAAA MM.MMMMMMM RRRRR
```

Field (Line 1)	Description
nnnnn	satellite SDC number
YY	year of launch
LLL	launch number of the year
AAA	International designator (piece of the launch for multi-payload launches)
YY	last two digits of epoch year
DDD.DDDDDDDD	epoch, as day and fractional part of day
0.XXXXXXXXXX	first time derivative of the mean motion
ZZZZZ	second time derivative of the mean motion
J	exponent of second derivative of mean motion
GGGGG	drag coefficient for SGP4 theory
K	exponent of drag coefficient
T	Ephemeris theory code; "0" is used for SGP4
SSSS	Origination code for TLES; this is set to "OATS" if generated by OATS

Field (Line 2)	Description
nnnnn	satellite SDC number
III.IIII	Inclination (degrees)
NNN.NNNN	right ascension of ascending node (degrees)
EEEEEEE	eccentricity (decimal point implied such that 0.eeeeeee)
WWW.WWWW	argument of perigee (degrees)
AAA.AAAA	mean anomaly (degrees)
MM.MMMMMMM	mean motion (revolutions per day)
RRRRR	5 digit revolution number (leading zeroes are shown for 4 digits or less)

8.1.5 RUK12 Input Files

The RUK12 orbit model accepts an osculating, Cartesian state vector as input. Although the components of the input state vector for this type of orbital element set are well defined, the orbital element set file does not have a fixed native format for those components. Note that fields within the same line can be space- or tab-delimited. The input file format for the RUK12 orbit propagation model that is used in OATS is as follows:

Line	Field	Description
1	x	x position component in kilometers (real)
	y	y position component in kilometers (real)
	z	z position component in kilometers (real)
2	xdot	x velocity component in kilometers (real)
	ydot	y velocity component in kilometers (real)
	zdot	z velocity component in kilometers (real)
3	year	epoch year (real)
	month	epoch month (real)
	day	epoch day (real)
4	hours	epoch hours (real)
	minutes	epoch minutes (real)
	seconds	epoch seconds (real)
5	frame flag	integer flag specifying ECI (0) or ECF (1) coordinates
6	step	step size in seconds for the numerical integrator (real)

8.1.6 J2 Input Files

The J2 orbit model accepts mean Keplerian orbital elements as input. Although the components of the input state vector for this type of orbital element set are well defined, the orbital element set file does not have a fixed native format for those components. Similar to the RUK12 input file format, fields on the same line can be space- or tab-delimited. The input file format for the J2 orbit propagation model that is used in OATS is as follows:

Line	Field	Description
1	A	semi-major axis in kilometers (real)
	e	eccentricity (real)
	i	inclination in degrees (real)
2	Ω or α	argument of the ascending node in degrees (real); see frame flag
	ω	argument of perigee in degrees (real)
	m or t	anomaly in degrees (real); see anomaly flag
3	year	epoch year (real)
	month	epoch month (real)
	day	epoch day (real)
4	hours	epoch hours (real)
	minutes	epoch minutes (real)
	seconds	epoch seconds (real)
5	frame flag	integer flag specifying ECI (0) or ECF (1) coordinates; if ECI, α is right ascension of ascending node; if ECF, Ω is longitude of ascending node
	anomaly flag	integer flag specifying mean anomaly m (0) or true anomaly t (1)

Charlie OLES
86622.6320071.8394858.00083.0002540.5181203.1292462.2360780940210
Z OLES
866221791163200716839485800008300025406518120371292462623607802920210
PME OLES
710398676193982778632018000040194434201979435850855661761975120330000
SGP4 TLES
1 88888U 80275.98708465 .00073094 13844-3 66816-4 0 8 2 88888 72.8435 115.9689 0086731 52.6988 110.5714 16.05824518 105
RUK12
2000.197 -6226.445 2912.336 2.6354727 3.5526063 5.8846738 1991 11 10 7 40 0.0 0 60.0
J2
6700.0 0.02 35.0 0.0 50.0 5.0 1993 11 1 0 0 0.0 1

Figure 8.1. Sample Orbital Element Data Files

8.2 Ephemeris Files

Ephemeris files generated by OATS contain header data followed by a consecutive listing of satellite state vectors (position+velocity) separated by a constant time increment. The files are ASCII character format with a sequential organization. If a user wishes to use an OATS ephemeris file in another application, it is necessary only to use an editor to strip off the header lines. The header is two to three lines, depending on the orbit propagator used to generate the file, and each line of the header begins with the word "OATS". The header allows the OATS software to access the ephemeris data more quickly. However, it is not a requirement for the ephemeris file to have a header for OATS to access an ephemeris. Ephemeris files generated by external software can be utilized if it has a constant time increment between state vectors and if it follows the record format described as follows. The ECF coordinate system is described in Section 3.2. Each line contains the following space- or tab-delimited fields:

Field	Description
YYYY	Year (integer)
MM	Month (integer)
DD	Day (integer)
hh	Hour (integer)
mm	Minutes (integer)
seconds	Seconds (real)
x	ECF x-position component in kilometers (real)
y	ECF y-position component in kilometers (real)
z	ECF z-position component in kilometers (real)
xdot	ECF x-velocity component in kilometers/second (real)
ydot	ECF y-velocity component in kilometers/second (real)
zdot	ECF z-velocity component in kilometers/second (real)

8.3 Target Files

The target input file allows the user to import a list of target positions into OATS for coverage analysis and provides a means to access multiple lists of targets for different types of analyses. A target file may be created by the user with any text editing program, or may be compiled using the OATS target interface and saved to a file using the *Save* option (see Section 6.6). The files are ASCII character format with a sequential organization. Each line must contain the data fields as shown below, with data fields delimited by at least one blank character or tab. Target names may be any 32-character alphanumeric string — they may be as simple as a number identification or may even be left blank provided the length is preserved in the file. Target names are not required to process targets within OATS, because a unique target is defined by a combination of all four data fields. The user is cautioned, however, that the interface used to display targets will show a blank line for a target with no name in the list where an alphanumeric name would normally be displayed. Targets with blank names can be processed, highlighted, and manipulated in such lists, but it is extremely awkward to differentiate between members of a list with blank name fields. Coverage analysis printouts may also be confusing as a result.

Field	Description
Name	target name, any 32-character alphanumeric string
Latitude	target geodetic latitude in degrees
Longitude	target longitude in degrees
Altitude	target height above the ellipsoid in kilometers

8.4 Ground Station Files

The ground station input file allows the user to import a list of ground station positions into OATS for coverage analysis and provides a means to access multiple lists of ground stations for different types of analysis. A ground station file may be created by the user

with any text editing program, or may be compiled using the OATS ground station interface and saved to a file using the *Save* option (see Section 6.7). The files are ASCII character format with a sequential organization. Each line must contain the data fields as shown below, with data fields delimited by at least one blank character or tab. Ground station names may be any 32-character alphanumeric string — they may be as simple as a number identification or may even be left blank provided the length is preserved in the file. Ground station names are not required to process ground stations within OATS, because a unique ground station is defined by a combination of all five data fields. The user is cautioned, however, that the interface used to display ground stations will show a blank line for a ground station with no name in the list where an alphanumeric name would normally be displayed. Ground stations with blank names can be processed, highlighted, and manipulated in such lists, but it is extremely awkward to differentiate between members of a list with blank name fields. Coverage analysis printouts may also be confusing as a result.

Field	Description
Name	ground station name, any 32-character alphanumeric string
Latitude	ground station geodetic latitude in degrees
Longitude	ground station longitude in degrees
Altitude	ground station height above the ellipsoid in kilometers
Elevation Mask	ground station elevation mask in degrees above horizon

8.5 Map Files

OATS contains an internal map database, which is adequate for the majority of map plotting functions for which OATS is typically utilized. However, OATS also provides the user the option of supplying his/her own map file for special mapping projects. A user's external map file should be in sequential ASCII format, and should be organized as a set of ordered data points that define geographic outlines in a "connect-the-dots" fashion. Such outlines would most commonly be provided for continental boundaries, large bodies of water, and major islands. However, the format does not preclude use of a map file with geo-political outlines. The use of visible versus invisible outlines allows solid areas to be plotted side-by-side without showing boundaries in an outline map. Record format is as defined below, with each data field being delimited by at least one blank character or tab.

Field	Description	Values
Latitude	Geodetic latitude in radians	$-\pi$ to π
Longitude	Geodetic longitude in radians	0 to 2π
Area Type Flag	One-character area descriptor	A negative longitude is used to signify the start of a new plot area G for land with visible outlines L for water with visible outlines g for land with invisible outlines l for water with invisible outlines

8.6 Contour Level Files

These files are used to store levels for either the line contouring function or for the density contouring function. It is recommended to use the OATS density interface to enter levels and colors and then do a *Save* to create a levels file (see Section 6.9). However, users may create their own levels file externally using a text editor. Contour level files have a sequential ASCII format and allow only one contour level per line. Levels are usually real number type data but can be integers. They should not be negative and should be listed in ascending order by level value. Three integer numbers follow the contour level to record the colors used for density contours; otherwise, all color values will be read from the file as zero valued which will result in all black density contours. These color values are not required for plotting line contours. Color level integers should be between 0 and 255, inclusive. Level and color numbers should be delimited in each record by at least one blank character or tab.

8.7 Contour Files

The OATS graphical coverage function (see Section 5.4) creates a tabular file of data which is then used to plot coverage isochrones or a color-coded density map of satellite coverage. This contour file can be written in compressed form to save storage space. However, the user can also save it in expanded character format for transport to other analytical programs or for direct inspection. If saved in expanded form, the file will be in sequential ASCII format and will consist of one line of header data followed by a number of data records dependent on the mesh size used by OATS to perform the graphical coverage run. The header record will have a character recognition string for OATS internal usage followed by two integers, k and l . These integers identify the number of latitude and longitude grid points in the coverage computation mesh. If n is the user selected grid spacing in degrees of latitude, then the number of grid elements on each meridian is $l+1$ and

$$l = 180/n$$

Likewise, if m is the grid spacing in degrees of longitude, then the number of grid elements on each parallel is computed:

$$k = 360/m$$

The remainder of the file beyond the header is made up of the $k(l+1)$ data records representing the grid points. The grid points can be mapped back to the latitude/longitude grid via the following algorithm:

For the p^{th} record in the file (after the header record):

$$\begin{aligned} \text{latitude} &= i * 180/l - 90 && \text{(in degrees)} \\ \text{longitude} &= (j-1) * 360/k && \text{(in degrees)} \end{aligned}$$

where

$$i = \text{int}((p-1)/k)$$
$$j = p - (i * k)$$

and the `int` function converts a real number to an integer value with truncation.

Each individual coverage record consists of five values representing the coverage level at its point in the mesh. In left-to-right order these data are:

- Cumulative coverage as a percentage of time
- Cumulative coverage as an average daily coverage (in minutes)
- Cumulative coverage as a total daily coverage value (in minutes)
- Average cover outage (minutes per day)
- Maximum cover outage (minutes per day)

OATS' contouring functions can also be used to plot data created by an external program, and which is not necessarily related to satellite coverage. An artificial contour file can be created as an input to OATS for this process. In this case, the header record in the data file to be contoured should consist of only the integers k and l as defined above. This type of header will not have the OATS recognition character string, which identifies for OATS that the file is externally created. The remaining $k(l+1)$ records to be contoured in the file should contain only one data value in ASCII character format. It is suggested that records created by external software use the following pseudo code:

```
Do for latitudes j=1,2,...,(l+1)
    Do for longitudes i=1,2,...,k
        Write contour value for latitude j and longitude i
    End Do
End Do
```

8.8 Attitude Files

A spacecraft's orientation can be defined in OATS through the use of attitude files. Although there is typically some association of ephemeris file to attitude file, it is not a requirement of the program that there be any pre-assignment. It is necessary that the time intervals overlap, but the interval between records need not be the same and the start and stop times do not need to be identical to those of the ephemeris file. All data is presumed to be stored in ASCII character format.

Attitude files have two header records, followed by n time-tagged attitude records. The first header record contains an integer mission number. The format is non-critical and can be followed by a delimiting blank space or tab and any user-defined data of interest. The second header record contains an integer flag (format again non-critical) identifying the type of data contained in the file. Appendix A elaborates further on this issue. The file types indicated by the flag are:

- 1 = pitch/roll/yaw data
- 2 = right ascension/declination
- 3 = perifocal X/Y/Z

Each subsequent line contains the following space- or tab-delimited data fields:

Field	Description
<code>time record</code>	DD-MMM-YYYY HH:MM:SS.SS
<code>angle1</code>	floating point number
<code>angle2</code>	floating point number
<code>angle3</code>	floating point number

The exact format of the time record is intentional and historical in nature — it matches the format of attitude files supplied to the authors of the software and used in their analyses. The various sub-fields in the time record imply day, month (e.g. SEP for September), year, hours, minutes, and decimal seconds. The specific definition of the angle data depends on the file type. If file type 1, angle data is pitch, roll, and yaw in degrees. If file type 2, angle data is right ascension and declination in degrees with angle 3 undefined and unnecessary. If file type 3, angle data are unitless vector components in the perifocal coordinate system. The convention for ordering the unit vector components is perigee direction, orbit normal direction, then orbit normal cross perigee direction.

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Acronyms

AOS	Acquisition of Signal
ECF	Earth Centered Fixed
ECI	Earth Centered Inertial
FOV	Field of View
GS	Ground Station
LOS	Loss of Signal
OATS	Orbit Analysis Tools Software
OLES	One Line Element Set
SDC	Space Defense Center
TLES	Two Line Element Set
WGS84	World Geological Survey 1984

Glossary

coverage time	The interval between Acquisition of Signal (AOS) and Loss of Signal (LOS).
elevation mask	For a ground station, the elevation mask defines the portion of the station's hemispherical horizon not visible to the station; it is the elevation above the horizon above which a satellite must rise before it can be viewed by a ground station.
herg	A unit of time measure commonly utilized in orbital mechanics; it equals 806.8120769 seconds and is the orbital period of an imaginary satellite rotating about the Earth at zero altitude.
isochrones	Lines connecting points on the Earth's surface that have equal values of time duration of satellite coverage.
outage time	The interval between LOS and AOS.
revisit time	The interval between one AOS to the next AOS.
swath	The area on the Earth's surface swept out by the field-of-view of a satellite as it rotates around the planet and scans over the surface.

Appendix A

Sensor Terminology

Antenna Patterns

OATS supports both nadir-pointing and non-nadir-pointing conical satellite sensor patterns as well as an annular satellite field-of-view, which is a variation on the conical sensor pattern wherein a conical "hole" exists centered in the antenna pattern. The sensor pattern is always symmetric about an axis known as the boresight direction. The viewing geometry for a nadir-pointing satellite is depicted in Figure A.1. In this diagram the boresight direction is Earth-centered, but this will not necessarily be the case when attitude data is used.

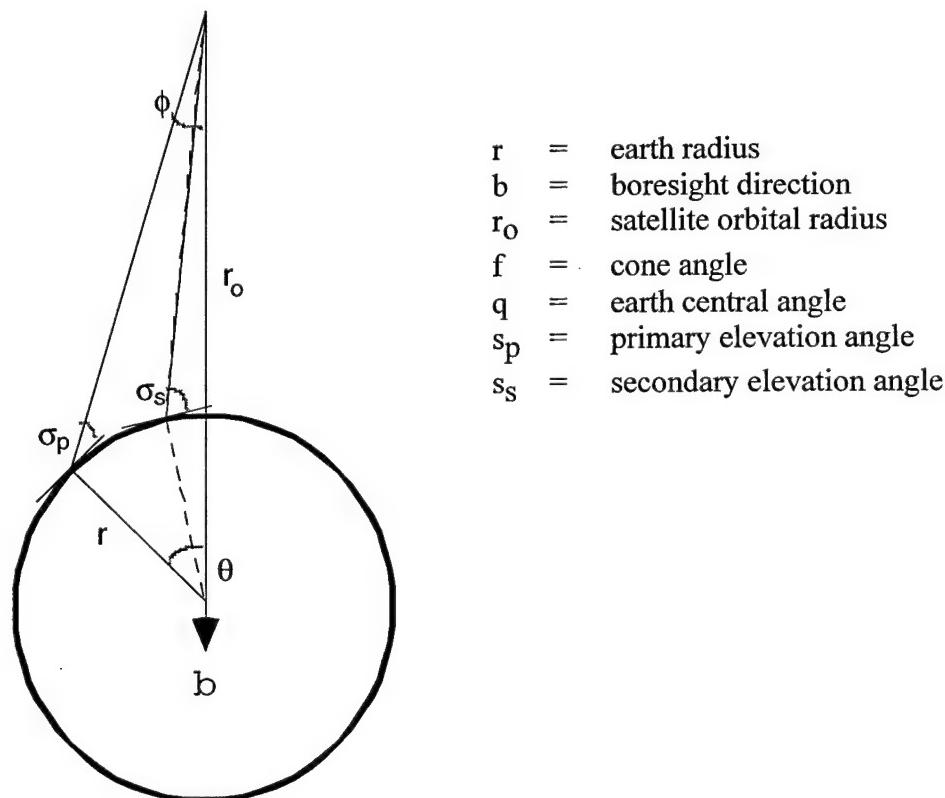


Figure A.1. Satellite Antenna Pattern Geometry

Where required under the *Plot* and *Coverage* menus, the user can define the sensor pattern by selecting an antenna type of cone angle, earth central angle, or elevation angle. For these cases, a single angle defines the sensor FOV. Program dialogs designate this single angle as the primary angle, even though no other angle is necessary. Selection of an antenna type that is annular requires specification of both the primary elevation angle

and the secondary elevation angle. It is required that the secondary angle specify the interior edge of the annulus and the primary angle specify the interior edge of the annulus. OATS will sort these two data inputs in order to maintain the required relationship.

Attitude Terminology

Spacecraft attitudes and the orientation that they impart to an antenna sensor are implemented in OATS by specification of the sensor boresight direction. Three possible coordinate systems are available in which to specify the attitude, including:

- Inertial System* (X, Y, Z) — The fundamental plane is the Earth Equator. The X direction lies in the fundamental plane in the direction of the Vernal Equinox. The Z direction is the North Pole, and $Y = Z \leftarrow X$.
- Orbit Local Coordinate System* (x, y, z) — x is in the direction of the velocity vector, y is normal to the plane of the orbit, and $z = x \leftarrow y$
- Perifocal Coordinate System* (X_w, Y_w, Z_w) — X_w points toward the orbit perigee, Z_w is in the orbit normal direction, and $Y_w = Z_w \leftarrow X_w$.

Within these three coordinate systems, OATS permits specification of satellite attitude in four ways:

1. Nadir Pointing
The sensor boresight direction is toward nadir. For circular orbits this corresponds to the $-z$ direction in the Orbit Local Coordinate System
2. Roll/Pitch/Yaw
The Roll / Pitch / Yaw system allows the sensor direction to be specified as a rotation about the orbit normal coordinate system. When using this specification type, the sensor boresight is rotated by the roll, pitch, and yaw angles away from the $-z$ direction. The rotation convention is taken in the following order: 1) pitch about y , 2) roll about (new) x , 3) yaw about (new) z . "New" x means the x direction after the pitch rotation, and "new" z means the z direction after the pitch and roll rotations. When the roll, pitch, and yaw angles are zero, the sensor boresight is in the $-z$ direction.
3. Right Ascension / Declination
The right ascension / declination system allows the sensor direction to be specified with respect to the inertial system X, Y, Z . The right ascension angle is measured in the equatorial plane from X in the direction of Y . The declination angle is measured from the X/Y plane in the Z direction.
4. Perifocal
The Perifocal system allows the sensor direction to be specified with respect to the satellite orbit. The direction parameters are simply X_w, Y_w , and Z_w , as defined by the perifocal coordinate system above.

Appendix B

Review of Orbital Elements

This users manual is not an appropriate vehicle for a comprehensive discussion of orbital elements or the mathematical models behind the various orbit propagators. However, the authors do furnish this section as a *basic* explanation of the terminology used to specify orbital elements. For an in-depth review of the derivations of the orbital elements, the user is directed to Reference 11. For a better understanding of the orbit propagators, see Chapter 3 and the references cited therein. The review of orbital element terminology applies throughout the document, but is especially relevant to the Section 8.1 discussion of orbital elements and the Chapter 3 discussion of the entry dialogs for orbital elements.

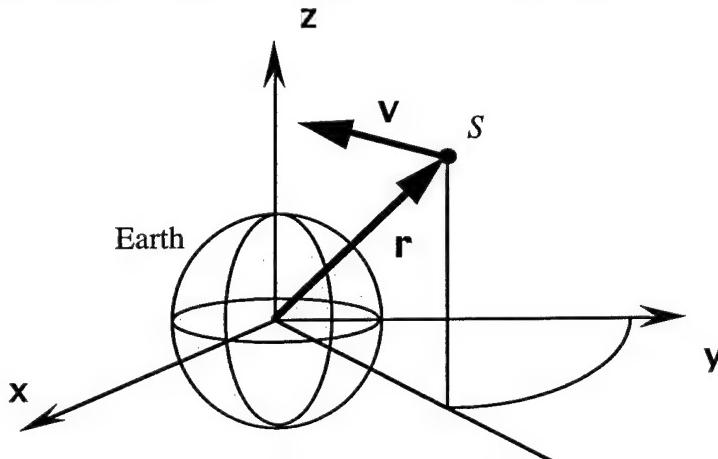


Figure B.1. Cartesian Representation of a Body in Space

The position of any satellite in space, S can be represented by its position vector $r(t)$ as shown in Figure B.1. If r is represented as the sum of its three-dimensional Cartesian vector components

$$r(t) = x(t) \hat{i} + y(t) \hat{j} + z(t) \hat{k}$$

then any motion of the body can be represented as the time rate of change of each of the vector components, or the velocity vector $v(t)$:

$$v(t) = \frac{dx(t)}{dt} \hat{i} + \frac{dy(t)}{dt} \hat{j} + \frac{dz(t)}{dt} \hat{k} = \dot{x}(t) \hat{i} + \dot{y}(t) \hat{j} + \dot{z}(t) \hat{k}$$

This simple formulation of orbital elements is the Cartesian state vector used by the RUK12 propagator. Orbital elements are specified by x , y , z , and \dot{x} , \dot{y} , and \dot{z} at a known point in time. The RUK12 propagator then takes the known position and velocity, combines them with the equations of motion, and repetitively projects the position and velocity at some small increment of time Δt beyond the known time. Only

two other factors are required to specify the RUK12 orbital element set. The first is a flag that defines if the supplied position and velocity vector components are given in the ECI or ECF coordinate frame (see Chapter 3). The difference between the two is a rotational coordinate transformation that accounts for the difference in the placement of the zero point in time as well as the rotation of the ECF system. The second factor is an orbit decay term, showing how much the orbit is shrinking over time. Decay rates for typical stable orbits are near zero and most often are provided as a small constant value if they are important at all. Decay rates can become large and non-constant for very low atmosphere-grazing orbits or in the presence of transient external forces like solar flares. In addition to the conceptual simplicity of the orbital elements, the RUK12 propagator has an advantage over the other available propagators in that it can propagate any trajectory. These advantages are offset by the fact that this propagator is computationally intensive and much slower than the other options available.

A somewhat more common approach to the problem of specifying the orbital elements for a spacecraft is to assume that the satellite is gravitationally bound to the Earth. Such a satellite follows a closed path that is a conic section called an ellipse. This simplifying assumption transforms the problem of specification of orbital parameters to one of specification of parameters that define the geometrical shape and orientation of the ellipse. Other non-closed conic section orbits are of course physically possible (e.g. parabolic or hyperbolic paths). However, with the exception of the RUK12 propagator, OATS orbit propagators are not relevant to such orbits. There are always minor deviations from a true ellipse in a satellite orbit that are caused by real-world factors such as atmospheric drag, solar radiation pressure, deviations of the Earth from a spherical shape, non-uniformities in gravitational pull on the satellite, or forces originating in the satellite itself like engine firings or outgassing. Some of the propagators available in OATS (e.g. SGP4) account for the largest of these deviations, but over time there will always be degradation of an orbit and evolution of the orbital elements. This is why every set of orbital elements is furnished with an epoch at which the elements were calculated and at which the elements are correct. The further in time that an orbit deviates from the source epoch, the larger the errors that can be expected to be found.

An ellipse is defined as the collection of points in a plane, such that for each possible point the sum of distances from two fixed points to the ellipse point is a constant value. The basic geometry of an ellipse is shown in Figure B-2. The center of the Earth will always occupy one of the defining points for the ellipse, known as a focus (F_1). The other focus (F_2) is empty, but for most real orbits this focus lies within the diameter of the Earth. The distance AB is the greatest diameter of the orbit, called the major axis. Both foci are equidistant from the center X and located on the major axis. The distance CD is the smallest diameter of the orbit, called the minor axis. AB and CD are the axes of symmetry of the ellipse, and meet at the center at X and cross at a right angle to each other. The distance AX or BX is known as the semi-major axis, a . This distance is also the mean distance of the satellite from the center of the Earth at focus F_1 . The stretching (or flattening) of the ellipse is measured by a unitless quantity called eccentricity, e . If c is the distance from the center to a focus, then:

$$e = c/a \quad \text{or} \quad c = a * e$$

A circular shaped orbit is merely a special case of the ellipse where $e = 0$. If S represents a satellite in Figure B.2 moving along its orbit at an arbitrary time t , then the position of the satellite can be specified by the angle f , the true anomaly.

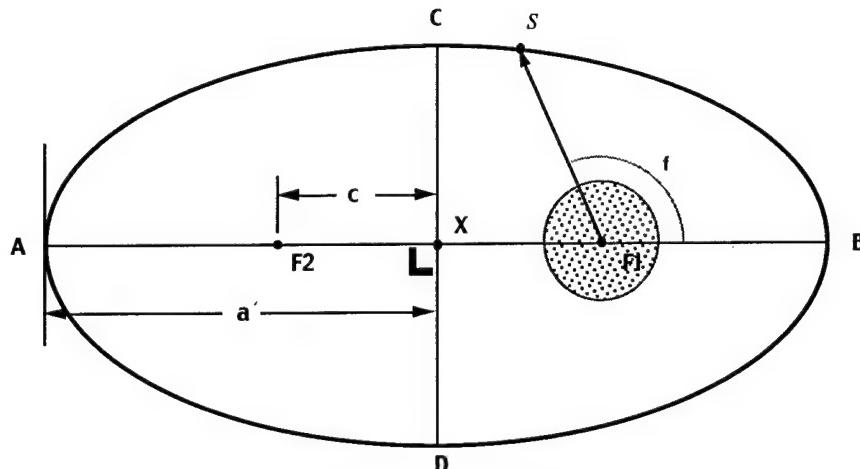


Figure B.2. Basic Geometry of an Orbit Ellipse

While the semi-major axis, eccentricity, and true anomaly are adequate to define the shape of the orbit they do not determine the spatial or temporal orientation of the ellipse relative to the Earth. The classical solution to this problem is to define three angles — an inclination i , a right ascension Ω , and the argument of perigee ω — as shown in Figure B.3.

For Figure B.3, the xyz Cartesian coordinate system is defined such that the xy plane coincides with the Earth's Celestial Equator (equatorial plane) and the +x axis is aligned with γ , the Vernal Equinox. Also known as the first point of Aries, γ is the point on the celestial sphere where the ecliptic (apparent path of the sun) crosses the celestial equator in the spring. The inclination angle i is the angle between the orbit plane and the Earth's equatorial plane. Inclination is measured around the line of intersection of the equatorial and orbit planes, also known as the line of nodes. This line connects the ascending node AN (the point on the equator where the satellite passes from the southern hemisphere to the northern) to the descending node DN (where the satellite passes from northern to southern). The angle Ω is the right ascension angle between the vernal equinox and the ascending node as measured in the equatorial plane. The third angle ω is the argument of perigee. It is defined relative to the perigee (perifocus), or closest approach to the central body around which the satellite is orbiting. The perigee is labeled point B. The argument of the perigee is the angle from the ascending node to the perigee measured in the orbital plane.

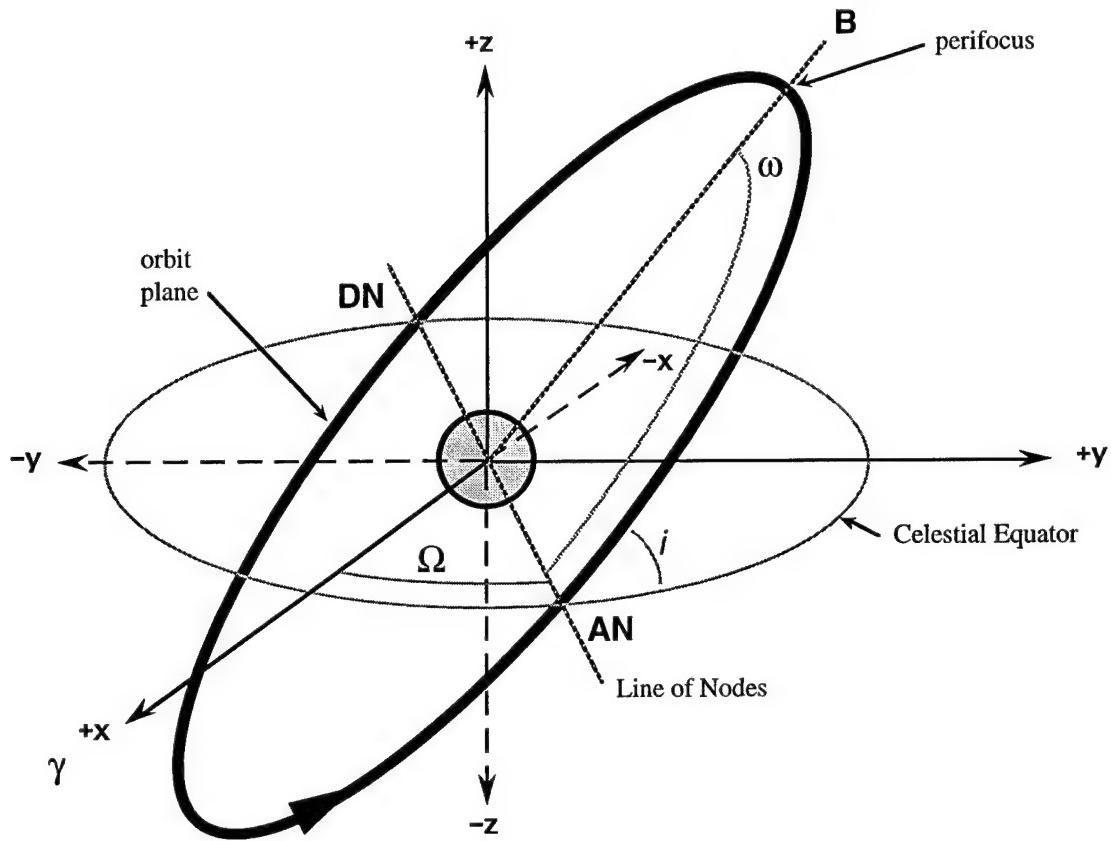


Figure B.3. Orientation of Orbit Ellipse Relative to Earth

The six coordinates of the ellipse, a , e , f , i , ω , and Ω are sufficient to completely specify an orbit, and can be used in conjunction with an epoch and a flag designating an ECF or ECI coordinate system for the orbital elements for the J2 propagator. However, these often do not represent the easiest formulation of the orbital elements with which to work.

Figure B.4 presents an alternative geometrical representation of the orbit ellipse, which is intended to complement the basic schematic presented in Figure B.2. In this figure, a circumscribing auxiliary circle is placed around the ellipse. P now designates the point of perigee. The geometry shows the auxiliary angle E , eccentric anomaly, which is introduced as an intermediate computational and comprehension step. Eccentric anomaly is defined as the angle measured in the orbital plane from the axis of perigee passage to a line containing the center and another point defined by the projection of the moving vehicle in the axis perpendicular to the perigee axis upon an auxiliary circle circumscribing the ellipse of satellite motion. In Figure B.4 the projection of the satellite on the circle is a fictitious satellite S_m . The mean angular rate of the satellite, called mean motion, is usually symbolized as n . Mean motion is the angular rate of the fictitious satellite as it travels around the circumscribing circle. By definition n is an easily specified constant value, whereas the true angular rate of the satellite around an ellipse varies with position on the ellipse. The mean anomaly, M , is another auxiliary

angle that physically represents the angular displacement of the fictitious satellite and the mean angular rate of the satellite. The quantities n and M represent the last of the orbital elements typically used as inputs for the J2, SGP4, and PPT2 propagators. Useful relations of these two quantities are as follows:

$$M = E - e * \sin E$$

$$n = 2\pi/\text{period} = \sqrt{\frac{\mu}{a^3}}$$

where μ is the combined mass of the satellite and the Earth, usually rounded to just the mass of the Earth.

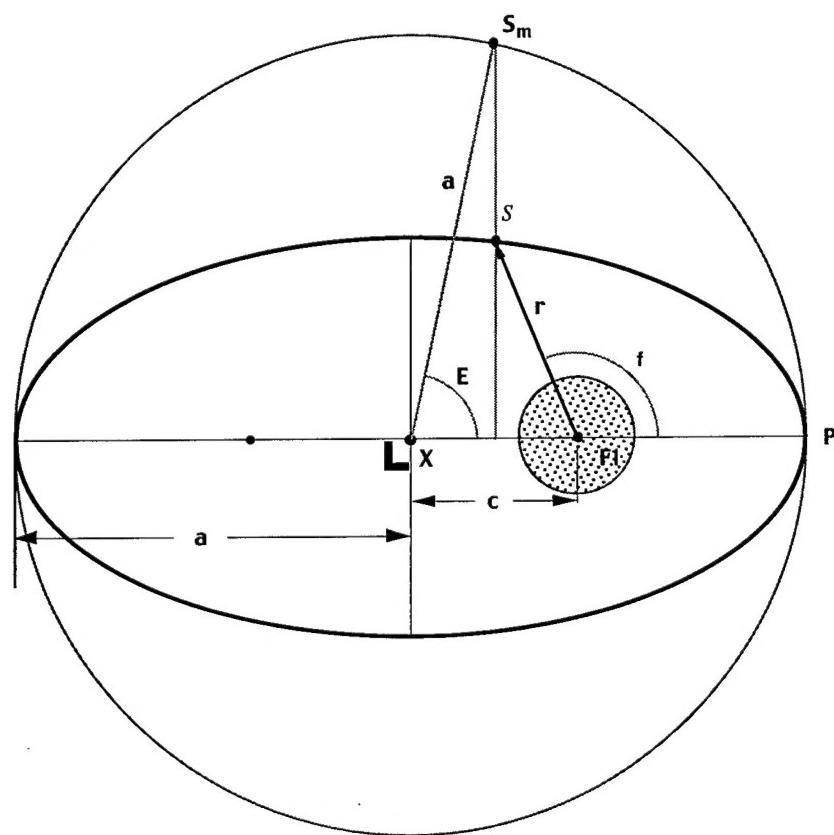


Figure B.4. Geometric Representation of Mean Motion

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